

Directors' Welcome

It is with great pleasure that we welcome you to the “Future of Nanotechnology” symposium. The symposium has two goals. First and foremost it is a celebration of the 30th Anniversary of the Cornell NanoScale Science and Technology Facility (CNF). For 16 years the nation’s only resource of its kind, and now part of the thriving National Nanofabrication Infrastructure Network, CNF has set the standard for nanofabrication facilities. Its contributions not only to nanoscale research, but also to education, outreach and economic development have been tremendous. This is a celebration of a major success story, which validates NSF’s foresight, the dedication of CNF’s staff, and the support of the CNF user community. Second, this symposium will help us prepare for the future by anticipating emerging trends in nanoscience and technology. Eminent experts from all over the world are present to give their perspectives on future trends in nanotechnology, the emerging field of nanomedicine, and the social and ethical issues associated with nanotechnology. In this meeting CNF continues to do what it does best – explore the technological future. We thank you for being part of our celebration and hope that you will enjoy and be stimulated by the symposium.

Warm regards,

George Malliaras, *Lester B. Knight* Director

Donald Tennant, Director of Operations

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Acknowledgments

The scientific program was organized by the following: Track I by Donald Tennant (CNF), Track II by Harold Craighead (NBTC) and George Malliaras (CNF), and Track III by Ana Viseu (CNF) and Ronald Kline (ECE and STS). Thanks are due to Professors Michael Schuler, Barbara Baird, Watt Webb, and Carl Batt for their input.

The administrative aspects of the symposium were overseen by Melanie-Claire Mallison (CNF) with the assistance of Gabriel Terrizzi and Jan Haldeman. Thanks are due to Lesley Yorke (KIC) for her valuable suggestions.

Front Page Photos: 1. Knight Lab, 1981 2. “Molecular Devices” Prof. Isaacson’s ebeam etching, 1981 3. “Transmission of the Signal for Cell Differentiation in the Fungus, *Uromyces*, H.C. Hoch and R.C. Staples; CNF Project #267-86, 1999 4. “In-Plane Alignment of Carbon Nanotubes Using Oblique-Oxide-Deposition”, S. Tiwari, J. VanDelden, H. Lin; CNF Project #804-99, 2006 5. Duffield Hall, 2007

Cornell NanoScale Science & Technology Facility

•30th Anniversary Celebration & Annual Meeting•

Thursday, June 14th, 2007

Morning Session: Call Alumni Auditorium, Kennedy Hall

7:30-8:30	Registration & Breakfast
8:30-9:15	Welcoming Remarks Edward Wolf, CNF Director 1978-1988 page 12 Lawrence Goldberg, NSF page 12 George Malliaras, <i>Lester B. Knight</i> CNF Director page 13
	Plenary Session Chair: Stephen Kresovich
9:15-10:00	nanoTech Plenary: <i>Manufacturing at the Nanoscale</i> R. Stanley Williams page 16
10:00-10:30	<i>Coffee Break - Kennedy Hall</i>
10:30-11:15	nanoMed Plenary: <i>Nanoscale Devices for Medical Diagnostics</i> James Heath page 17
11:15-12:00	nano&Us Plenary: <i>Constituting the NanoScale: Lessons from the 20th Century</i> Sheila Jasanoff page 18
12:00-1:30	<i>Lunch - Duffield Hall Atria</i>

Afternoon Sessions:	nanoTech Phillips Hall 101 <i>Donald Tennant</i>	nanoMed Phillips Hall 203 <i>Harold Craighead</i>	nano&Us Phillips Hall 219 <i>Ronald Kline</i>
<i>Session Chairs:</i>			
1:30 - 2:00	Phaedon Avouris p.19 <i>Carbon Nanotubes: Electronics and Optoelectronics in One Dimension</i>	Maish Yarmush p.25 <i>Real Time Genomics for Analyzing Dynamic Cell & Tissue Processes</i>	David Guston p.31 <i>Anticipatory governance and reflexivity: A means for real-time technology assessment</i>
2:05 - 2:35	Robert Corn p.20 <i>Utilizing Surface Enzyme Chemistry, Plasmons and Nanoparticles for Ultrasensitive Biosensing</i>	Mehmet Toner p.26 <i>Microchips for Cell-Based Systems in Biology and Clinical Medicine</i>	Juergen Altmann p.32 <i>Mind the Gap: Social and Ethical Research in Nanotechnology and International Security</i>
2:40 - 3:10	John Rogers p.21 <i>Approaches to Three Dimensional and Molecular Scale Nanofabrication</i>	Tejal Desai p.27 <i>Nanostructured Interfaces for Therapeutic Delivery</i>	Rosalyn Berne p.33 <i>Science Fiction as a Portal to Ethics in Nanotechnology</i>
3:15 - 3:45	Coffee Break Duffield Hall Atria	Coffee Break Duffield Hall Atria	Coffee Break Duffield Hall Atria
3:45 - 4:15	Stephen Chou p.22 <i>Nanostructure Engineering: A Path to Discovery, Innovation, and Commercialization</i>	Michael Sheetz p.28 <i>Understanding Cellular Mechanics Through Nanotechnology</i>	Douglas Kysar p.34 <i>Ecologic: Complexity, Cognition, and the Regulation of Nascent Technologies</i>
4:20 - 4:50	Gregory Timp p.23 <i>A Tiny Revolution: New Tools for Synthetic Biology</i>	Christopher Murphy p.29 <i>Biologic Length Scale Topographic Features Modulates Cell Behavior</i>	Priscilla Regan p.35 <i>Social and Ethical Dimensions of Nanotechnology: Research and Education Activities</i>
4:55 - 5:25	Christopher Jacobson p.24 <i>Nanostructures and X rays for Nano Characterization</i>	Dorian Liepmann p. 30 <i>When Bio-Molecules Affect Flow</i>	Panel Discussion: <i>Stephen Hilgartner, Session Chair</i>

5:30 - 7:30 Poster Presentations & Reception - *Poster Awards Presented at 7:00*
Duffield Hall Atria

A Personalized Summary of CNF History

National Research and Resource Facility for Submicron Structures (NRRFSS), 1977-1986

National Nanofabrication Facility (NNF), 1987-1993, as part of NNUN 1994 -1996

Cornell Nanofabrication Facility (CNF) and part of NNUN, 1996-2002

Cornell Nanoscale Science & Technology Facility (CNF) and part of NNIN, 2003-Present

Edward Wolf

Director of NRRFSS and NNF (1978-1988)

Professor, School of Electrical Engineering (1978-1991)

Professor Emeritus (1991)

Cornell University

In the beginning

The Cornell NanoScale Science & Technology Facility (CNF) had its beginnings within the National Science Foundation (NSF) during the mid-1970s. During 1976 NSF held three workshops across the country to assess the need and requirements for a university-based national research and resource facility for submicron structures (NRRFSS). These workshops were held at Washington University, St. Louis (May 3), University of Pennsylvania, Philadelphia (May 10) and University of Utah, Salt Lake City (May 21). Reports on these three workshops submitted to NSF may be accessed at CNF. I chaired the session on “The State of Submicron Technology” at the Washington University workshop so I am more familiar with that workshop. There was general consensus at all three workshops on the need and objectives for such a center. There was somewhat less general consensus on the establishment of a single center if funding did not permit two centers. Funding recommendations ranged from more than \$1M-\$2M/year for a center at the May 3 workshop, to \$5M to initially equip each center and a research budget of \$1M/year for at least 5 years at the May 10 workshop. The discussion at the last workshop, May 21, was documented with so much depth and focused on the requested NSF issues (it produced a report of 170 pages compared to the other two with 24 pages and 56 pages, respectively) that it is hard to find a recommended budget. However, on page 159, the report suggests that two centers, each costing about a million dollars (/year?), and that would include an e-beam machine as good as outlined for “somewhere in the \$350,000 class.” As a result of the strong support and consensus for a national user facility, NSF issued a request for proposals in late 1976.

Before describing the NSF announcement, it might be instructive to broaden the perspective horizon of submicron technology in 1976. Japan was investing heavily in submicron technology with its large new VLSI initiative. Several industrial/governmental research labs in the USA (IBM, Bell Labs, TI, HP, Westinghouse, Lincoln Labs, Hughes Research Labs), UK (Cambridge Instrument Company, Mullard Research Labs), France (Thomson CSF), Austria (Ion Microfabrication), Japan (Toshiba, Hitachi and others), and within Russia a few labs were exploring new shorter wavelength lithographies of e-beam, ion and x-ray. Leading

the effort was IBM across the board and particularly in e-beam technology; Bell Labs came on strong with the MEBES prototype for mask making using a raster scanned electron beam combined with a moving precision stage, which Etec Corporation exploited commercially quite successfully for many years. At Hughes Research Lab we had an early, but much smaller, effort with stimulus from satellite and weapons systems that required unique components, e.g., in target acquisition (charge coupled devices) and in signal processing (L- and X-band surface acoustic wave devices) as well as an emerging in-house new doping process called ion implantation that was to become part of the higher resolution “tool kit” for device miniaturization. Fortunately, the components used in the Hughes satellite systems were made by photolithography, so we at the Research Labs had the freedom and enjoyment of exploring what we could do with scanning electron beam lithography with the promise of great things for the future. But there was urgency behind our research. After all, photolithography was soon going to hit the Raleigh limit of resolution at about 0.2 μm and would soon be out of business!

This was the year of the first Gordon Conference on the Chemistry and Physics of Microstructures fabrication, which was chaired by Dr. Bob Keyes of IBM. Bob asked me to be his vice-chair and help organize the meeting. I thereby became chair-designate for the 1978 Gordon Conference. Attendance at both the 1976 and 1978 Gordon Conference was excellent.

Several universities were also leading the way in microstructure fabrication, for example UC Berkeley, Cambridge University, Tübingen University, and Osaka University to name just four from four different countries. But these and a few others were the exceptions, and most universities had not become involved yet. However, interest was growing as indicated by the NSF workshops and many engineering faculty members were seeking access to microstructure fabrication. Prof. Jay Harris at the University of Washington sought out our group at Hughes to see if he could get some microstructures made in Malibu. Our lab director declined our involvement for valid reasons. Later Dr. Harris joined NSF (1974) and participated in and helped promote, along with Dr. Gene Chenette, Head of Electrical Engineering and Dr. Tom Meloy, Division Director for Engineering, the early concepts of a national users facility for microstructures fabrication, which purportedly was supported by Dr. Edward Creutz, Deputy Director of NSF. Indeed, one can read in the December 15, 1975, Provisional Minutes of the National Science Board, “Dr. Creutz pointed out that the project [National Research and Resource Facility

for Microfabrication] involves an extremely interesting situation entailing the prospects of opening up entirely new concepts in engineering.” The Board unanimously approved at this meeting the continuation of discussions with the relevant community concerning the need and desirability for establishing such a center, but to report back before going forward with issuance of Request for Proposals. Later, in 1977, Gene Chenette was the initial NSF representative for NRRFSS, and then later Jay became the NSF program director for NRRFSS.

The objectives as put forth in the NSF Project Announcement (76-41) in 1976 for the new NRRFSS were:

- 1. To foster research on methods for building sub-micron structures, and to encourage expansion of the science base needed for sub-micron engineering;*
- 2. To provide a facility where research workers with different types of science or engineering background and from many different institutions can build experimental structures, devices and systems needed in research, which involves sub-micron dimensions;*
- 3. To establish a center of expertise in sub-micron structures design, which will serve as an information resource for the research community.*

The budget for the first year was not to exceed \$2 million and the total for the entire five-year period was not to exceed \$5 million. The winning proposal from Cornell University was promoted and coordinated by Prof. Joseph M. Ballantyne, School of Electrical Engineering. The three other finalists were UC Berkeley, MIT and Lincoln Labs, a University of Colorado partnership and National Bureau of Standards at Boulder.

To facilitate the creation of the NRRFSS in 1977, Cornell appointed Prof. Ballantyne as acting director, assembled a Program Committee to advise Cornell on equipment and program issues, and rallied faculty to respond to the 5-yr \$5-million grant which provided for \$2 million in equipment purchases and \$750 thousand/year for four years of program support. Prof. Paul McIsaac (EE) chaired the initial Program Committee and its members were selected from both academia and industry: Profs. W.S.C. Chang (Washington University) and T.H. Henderson (U. of Cincinnati), Drs. A.N. Broers (IBM Yorktown), R.F.W. Pease (Bell Labs), and E.D. Wolf (Hughes Research Labs). Dr. E.R. Chenette and later, Dr. Jay Harris, were the NSF representatives and Profs. J.M. Ballantyne (EE), B.W. Batterman (Physics), G.C. Dalman (EE), L.F. Eastman (EE), C.A. Lee (EE), A.L. Ruoff (Material Science and Engineering), and B.M. Siegel (Applied and Engineering Physics) were the Cornell representatives. We outside industrial members were keen on making sure the facility would have the best scanning electron beam lithography equipment available commercially. A Policy Board was also created to give long-range guidance to the facility. Its members at the end of the first year were Prof. T.E. Everhart (UC-Berkeley and later Dean of Engineering at Cornell) and Drs. G. Moore (Intel), K. Patel (Bell Labs), and H. Caswell (IBM).

Each major equipment purchase was the focus of one or more faculty members who determined the capabilities and best vendor. The mode of offering research and resource capabilities was to be through graduate students and a small support staff. The facility was to be located in renovated space (fourth floor) Phillips Hall, home of the School of Electrical Engineering, at a cost of about 600 thousand dollars.

Building a User Facility

I became a candidate for the directorship in 1977 and joined Cornell in July 1978 as professor in the School of Electrical Engineering and director of NRRFSS. Both Cornell and UC Berkeley had inquired of my interest in NRRFSS during the competition phase. During the first several years my focus as director was to design and build a clean room facility that would be functional and durable for the tasks before us and to create a user staff. Clean in this case meant low vibration and minimum AC ambient electromagnetic fields as well as Class 10 processing. Creating a user staff meant securing an adequate full-time technical staff to operate, repair, and maintain key equipment with acceptable up time, while interacting collegially and professionally with users both at Cornell and from other universities. The latter was key for a national user facility and for more effective use of the growing capital equipment investment (replacement price in 1986 was about \$30 million). So later on we began the transition from individual faculty and their graduate students to staff responsibility for equipment operation and repair. But initially we transitioned from a planned addition to the 4th-floor space in Phillips Hall to a new site on ground level for the new lab, which would provide a much quieter environment both electrically and physically. Necessarily, the price tag for both NSF and Cornell went up dramatically. We built a \$4.3 million dollar facility, with a 7,500 sq. ft. clean room, which we moved into during the fall of 1981 with minimum downtime and minor user program disruption. We designed the facility for about 60 users. However, we did not anticipate (and I have never fully understood) the elasticity that can be accommodated in order to retain NSF funding as we expanded to several hundred users in Knight Lab prior to moving into Duffield Hall! The new Knight Lab in 1981 provided local Class 10 processing in a Class 500 ambient, less than 1 milligauss electromagnetic ambient fields, and mechanical vibration of less than 50-nm amplitude at 1 Hertz on specialized concrete inertial slabs that were nearly a meter thick and isolated from the building. These were used for the vibration-sensitive electron beam systems. Lester B. Knight (Cornell '29) for whom the lab was named donated a majority of the construction costs.

By our fifth year (1982) we had gradually increased the annual budget from NSF to about a \$1.6 million – about double the original annual program grant. But the going was tough and renewal was not guaranteed.

We had excellent financial support and encouragement from Cornell administration, namely Deans of Engineering Edmund Cranch, Acting Dean, Andy Schultz, and later Thomas E. Everhart, Provost W. Keith Kennedy, and Presidents Frank H.T. Rhodes and Dale Corson. The early years of significant

growth and transition was also greatly assisted by the interest and support of a core group of Cornell faculty from the School of Electrical and Computer Engineering, School of Applied and Engineering Physics, and The Department of Materials Science and Engineering.

Prof. Ballantyne created and helped promote the industrial affiliates program called the Program on Submicron Structures or PROSUS during the second year of the grant which would grow to a peak membership several years later of about 44-member companies and provide more than \$0.5M dollars of annual support to the total operating budget, which averaged somewhat less than \$4 million during the mid to late 1980s. Profs. Jeffrey Frey and Peter Krusius served as assistant directors for PROSUS after Prof. Ballantyne, respectively. Prof. Robert Buhrman joined NRRFSS in 1980 as a much-needed associate director focusing on a variety of issues including the user program and stayed on for three years.

One key feature of the initial and continuing facility grants from NSF has been its catalytic effect of bringing outstanding senior faculty and staff to Cornell University. I list here, in approximate chronological order, the names of faculty and staff who were attracted to Cornell, in large or small part, by NRRFSS, NNF, and CNF: (There are others including postdocs with other faculty members not mentioned here.)

- *Edward Wolf, Electrical and Computer Engineering*
- *Thomas Everhart, Dean of Engineering*
- *Illesanmi Adesida, Electrical and Computer Engineering*
- *Michael Isaacson, Applied and Engineering Physics*
- *James Mayer, Materials Science and Engineering*
- *Peter Krusius, Electrical and Computer Engineering*
- *Noel MacDonald, Electrical and Computer Engineering*
- *Harold Craighead, Applied and Engineering Physics*
- *Alton Clark, Associate Director, CNF*
- *Sandip Tiwari, Electrical and Computer Engineering*
- *Donald Tennant, Director of Operations, CNF*

Much has been said about the supportive and structural environment of the old Materials Research Center (MRC) here at Cornell as the main reason for Cornell winning the NSF grant, and for the success of NRRFSS. I strongly agree with the first part, but mildly disagree with the latter part of the statement. The MRC structure and culture with faculty in charge of major instruments that were to be made available to outside users made it difficult in a few instances for NRRFSS to become a “neutral” national user facility. It took several years to create the funding and the “national” user concept required to wrest successfully several key instruments from the control of a few faculty members who believed in their programs first, other Cornell faculty next, and then “outside” users. I will quickly add that NSF and the outside user community had just the reverse order of priority. This was not a stress-free time for the director of NRRFSS. I have a thick file and little remaining hair to attest to this fact. Fortunately, this was the exception and may have had nothing to do with MRC culture: most faculty members were

quite supportive of the NRRFSS’s mission. On the positive side, having the faculty initially responsible for specifying, ordering, operating, and in some cases, developing special equipment was quite effective in giving the facility a fast and technically astute start.

Later as the facility assumed full responsibility for the equipment and its use, the early staff labored under a somewhat second-class citizenship as viewed by some Cornell faculty. But with time and demonstrated expertise, the staff of CNF has gained nearly the full confidence of all users. The staff has mastered the art and methodology of addressing the fabrication of microstructures in multidisciplinary research where each microstructure often requires its own unique vertically integrated processing. This is a tremendous accomplishment when you understand fully what this means: the use of 5 or 6 instruments multiple times within a period of perhaps a few days to one week with perhaps 5 to 20 other users also scheduled on the same 5 or 6 instruments. Obviously, all of the systems have to be up and working at expected levels of performance, which varies with user. Think 6 instruments by 24-hour matrix over-laid with 10 users for scheduling with no instrument failures and no human error! Impossible. But year after year the projects become more complicated, the instrumentation more sophisticated, the number of projects larger, and microstructures were becoming nanostructures.

Because NRRFSS was a new concept and was not an academic department, I tried to make employment at NRRFSS special. I was able to secure a salary pool that was just a bit higher than average at Cornell since NRRFSS was competing for staff with industry. I encouraged staff members to enter Cornell employee degree programs. Several did and graduated. We allowed a high degree of flextime, but still most staff would re-appear at reasonable times in the morning after working with users sometimes to 1 to 2 AM earlier in the same morning. We designed the Knight Lab to be user and staff friendly. The conference room was a special gathering room for staff and visitors in the best sense of the word. It was also a viewing room for part of the clean room and provided a bit of remote control of users by staff via the telephone service from conference room to clean room. With respect to another aspect of staff-friendly old Knight Lab, let me just say that the double occupied 11’ x 11’ staff “offices” either produced very close friendships or precipitated frequent trips to the conference room for relief, or better yet more frequent trips to the clean room with a user.

Evolution and Franchising of NRRFSS and NNF

Over the next 25 years (1982-2007), the number of staff grew slowly with the growth in NSF funding (which has averaged about \$36k/yr and now stands at about \$2.5 M/year through NNIN). However, the number of user projects continued to grow more rapidly as the staff became more efficient, and users more knowledgeable, in large measure because of the increase in the orientation and training classes provided by the staff. An early snapshot in time: In 1984 we had 96 user projects which were about equally divided between outside and Cornell and 10 facility development

research (FDR) projects; total involvement included 37 outside grad students, 45 outside faculty, 24 industrial or national lab scientists, and 105 Cornell grad students, 34 Cornell faculty and 23 Cornell research associates for a total of about 268 personnel using the facility. The applied metrics for measuring success evolved toward more user projects and few to finally no FDR projects. Our local review process was eventually relaxed and new user projects were undertaken if the user had the funds to come and if NRRFSS could do the work. Initially, user fees were discouraged for university users, in part, because funding agencies and investigators had not included user fees in their grants. It took a few years for this to happen. There was a brief snafu regarding no university user fees at NRRFSS. It became apparent to some NSF supported Regional Analytical Instrumentation Centers that did charge user fees that we were undercutting their business. We therefore, initiated user fees that were at or above industrial levels. The importance of user fees to the financial support of NRRFSS was enhanced by the gradual decline of the PROSUS industrial affiliates program, which essentially ceased to exist after about 1994.

Directors come and go, but the long-term success of the facility is primarily the result of talented and persevering staff members who often work well into the night during the short visits by researchers from other institutions. CNF staff members must astutely bridge the gap between wishful thinking by users and what is possible. They are, or become, the resident experts in the implementation of their particular area of nanofabrication. The user generally leaves satisfied and impressed, and the facility advances in its capability with a greater appreciation of the wide range of user needs. There is a quotation, which, I believe, is embodied in the work ethic of the CNF staff. The quotation is found in the south entrance to the Statler Hotel complex on campus, and reads, "Life is service – the one who progresses is the one who gives his fellow man a little more – a little better service" and is attributed to E.M. Statler. The facility has indeed progressed by the sweat of their brow and their dedication. [Please refer to Appendix A for a list of CNF staff members of record and their areas of responsibility.] We have had considerable input from a variety of sources in generating this list of past and present staff members, and we know the list is not yet complete. Please let let Melanie-Claire Mallison at CNF know of the omissions or errors in the list. This is an important record and we are dedicated to making it complete and accurate.

While all staff members deserve to be mentioned by name and are in Appendix A, I will dangerously choose to highlight seven at this point. I had the privilege of hiring all but one of the seven, and have worked closely with all. I believe they collectively represent the personality and character of CNF. Rich Tiberio was enticed away from IBM Fishkill in 1979 after only a couple of years out from getting his M.Eng. degree at Cornell to become the facility's scanning electron beam lithographer for 21 years. He left in 2000 for IBM Almaden in San Jose, CA. Rich was one of those who choose to do a Cornell Employee's degree with me and received his

Ph.D. in 1994. Dr. Illesanmi Adesida joined NRRFSS in 1979 as an IBM Postdoctoral Fellow from UC - Berkeley (Ph.D. with T.E. Everhart). He was the consummate faculty liaison research person and created many exciting collaborative research projects, which resulted in a significant number of publications he co-authored with a several faculty members here at Cornell. He soon became a research associate, then a visiting assistant professor, and several of us hoped to have him stay on at Cornell as a tenured-track faculty member. When that did not happen it was Cornell's loss and University of Illinois's gain. He is now Dean of the College of Engineering at Urbana. Nellie Yeh-Poh Lin Whetten became a pillar of technical skill and leadership as the early photolithographer at NRRFSS. This was after I convinced her that doing so would be more exciting than teaching math in the Newfield school system. She had received her master's degree in materials science at MIT after immigrating from Malasia and brought tremendous knowledge and skills to the position. She became one of the most respected and appreciated staff members of NRRFSS. Shortly after leaving NRRFSS with her husband, Tim Whetten, for jobs with HP in Loveland, CO, she was killed in an automobile accident. We established with the Whetten family, the Nellie Yeh-Poh Lin Whetten award, which is given annual to the outstanding female graduate student doing research at CNF who exhibits those special professional and personal qualities of Nellie as stated in the award requirements. [Please refer to Appendix B. List of the Nellie Yeh-Poh Lin Whetten Award Recipients.] Dr. Gregory Galvin served as associate director from 1984 to 1986, and as deputy director from 1986 to 1989. He was an effective administrator prior to, during, and after my sabbatical leave at Cambridge University in 1986-87. He led and contributed significantly to many aspects of the facility's growth and operation. He is now CEO of Kionix, Inc., an Ithaca based MEMS company. Dr. Lynn Rathbun has become the 'senior' facility staff member having been there in the beginning, and has contributed significantly to the implementation of the NNUN and NNIN (see later), to other critical proposals, and to the documentation of CNF accomplishments over the years. He is the CNF Laboratory Manager and the NNIN Program Manager. Mike Skvarla, also a staff member of long standing, serves as the CNF User Program Manager and is the friendly and well-informed welcoming hand that is extended to all users at CNF. Finally, Melanie-Claire Mallison may not have originated the Research Experience for Undergraduates (REU) Program (that honor goes to Phyllis DeFano, Meg Hardy and Dr. Lynn Rathbun in 1990, and to Dr. Alton Clark for the idea of franchising it across NNUN), but she does deserves the credit for its great success. It is now a major program within NNIN. A measure of its success: In 1990 there were 30 applicants and 9 participants, in 2007 there were 600 applicants and 82 participants, and it is estimated that about 40% of the participants end up in graduate school at one of the NNIN universities.

NRRFSS evolved at Cornell from a College of Engineering facility to a University facility (1987), and in name from the National Research and Resource Facility for Submicron

Structures to the National Nanofabrication Facility (1987). Prof. Harold Craighead, School of Applied and Engineering Physics (recruited from Bellcore) became the second director of the facility in 1989. Harold also became the first Lester B. Knight director, as a consequence of the Knight family endowment of the directorship during his tenure.

In 1993-1994, Cornell University participated in the creation of the National Nanofabrication Users Network (NNUN) with the Cornell Nanofabrication Facility as a key facility along with Stanford in a five-university network of user laboratories; Cornell, Stanford University, University of California at Santa Barbara, The Pennsylvania State University, and Howard University. The successful creation of NNUN became reality only through guidance by NSF, and the skill and hard work put forth by Dr. Norman Scott, then VP for Research at Cornell and Dean James Gibbon at Stanford and Profs. Harold Craighead (CU) and Jim Plummer (Stanford). Dr. Alton Clark joined CNF (April 1994) shortly after NNUN was established (January 1994) as associate director of CNF. Dr. Clark, formerly a professor of physics at U. of Maine, VP for Research at Carborundum, and a Ph.D. Cornellian, provided expert managerial and executive leadership over a period of about six years and bridged the transition of three CNF directorships, which included serving twice as interim director of CNF.

In May 1994, Cornell Profs. Harvey Hoch, Lynn Jelinski, and Harold Craighead organized a highly successful and, in retrospect, a pivotal workshop entitled, "Nanofabrication & Biosystems: Integrating Materials Science, Engineering & Biology," which was held in Hawaii. It is not clear whether the title or the location was the main draw for the large attendance? What is clear is that things began to change rapidly in the biotech community. At Cornell the rumblings were heard and groups began to form around what would become the Nanobiotechnology Center (NBTC) at Cornell in 2000. Later NBTC took its place along side CNF in Duffield Hall when it opened. Earlier CNF hired Dr. Gregory Baxter to focus specifically on the needs of the biology users.

Prof. Noel C. MacDonald, School of Electrical and Computer Engineering, served as the acting director in 1986-87 during my sabbatical leave of absence and later as the third director of the facility from 1995 to 1997 when he left to assume a position at DARPA. As mentioned earlier Dr. Alton Clark served as interim director of CNF. This was at both ends of Prof. MacDonald's directorship. Prof. Joseph M. Ballantyne served as the Lester B. Knight Director of CNF from 1998 to 1999, when Dr. Sandip Tiwari accepted the directorship, recruited from IBM.

In 1998, NNUN was notified of another five years of funding. It was only fitting that Prof. Ballantyne, who was key in winning the original 1977 competition for the facility, was at the helm as director when CNF was awarded this continuation of funding as part of NNUN. NNUN served quite successfully as a model for national networks of user research facilities, and set the stage for an even larger nanotechnology network to come, NNIN.

In 2003, Cornell University was fortunate to have Prof.

Sandip Tiwari, the Lester B. Knight Director of CNF, take leadership of the effort that won the National Nanotechnology Infrastructure Network (NNIN) competition. This expanded network includes 13 sites; Cornell, Georgia Institute of Technology, Harvard, Howard, Pennsylvania State, Stanford, University of California at Santa Barbara, University of Michigan, University of Minnesota, University of New Mexico, University of Texas at Austin, University of Washington, and Triangle Lithography Center (NCSU/UNC). Today, NNIN serves a total of about 4,400 users/year (growing at a double digit rate) of which CNF serves nearly 750 regular users/year across a broad range of subject areas. More than 70 faculty members from Cornell and a similar number from other academic institutions, nearly 550 graduate students, 300 of whom are from Cornell, and 200 industrial users. With Prof. Tiwari as Director of the new 13-member network, and with CNF continuing a key leadership role, the impact of NNIN can be felt across the country's nanotechnology landscape.

Prof. John Silcox served, as always in a strong supporting role for CNF, as the interim director of CNF in 2005-2006 while Cornell was searching for new leadership for CNF and Prof. Tiwari was on sabbatical leave at Harvard. [Please see Appendix B for a chronological list of CNF directors.]

Critical to a successful research initiative is the management of funding and the oversight of the nation's taxpayers' money. The National Science Foundation has been there from the very beginning and remains an effective guiding influence to this day for CNF, NNIN and nanotechnology in the broadest of perspectives. At the time of the establishment of NRRFSS, NSF was itself in transition. The Directorate for Engineering was just being established with Dr. Jack T. Sanderson serving, I believe, as the acting director. One of the concerns early on was how much NRRFSS was draining funding from individual grants within the microstructures program at NSF (i.e., big science versus small science). Fortunately, the Engineering Directorate moved on to create a number of differently named centers, e.g., Engineering Research Centers, to the great benefit of engineering and the nation. Key to this important stewardship and to the success of the facility is the many past NRRFSS/NNF/CNF program directors. I would like to name two in particular, Prof. Dr. Ronald J. Gutmann, Professor from Rensselaer Polytechnic Institute, and Dr. Donald J. Silversmith, Physicist and Manager, from Lincoln Labs, MIT. [Please see Appendix D for a chronological list of the NSF program directors that have had program oversight for NRRFSS, NNF, and CNF] They both served admirably and astutely, from my perspective, as NSF program directors. Prof. Ron Gutmann served during an early key period 1981-82 in the history of NRRFSS as it was defining itself and making its way through uncharted territory, including its preparations for a 5-year renewal for funding by NSF. Don Silversmith provided excellent interface between NRRFSS and NSF as we changed our name to the National Nanofabrication Facility (NNF) in 1987, celebrated our first 10 years of success, and re-applied for funding from NSF. We also verified our approximate 1:1

matching of NSF funds (better than most, if not all centers), which was being questioned erroneously at high levels within NSF, apparently because we (I) at Cornell had declined a major piece of equipment from a major corporation. Another issue was facility development research programs to enhance equipment and processes within NRRFSS, which were later eliminated by peer pressure and by the need for NSF funds for equipment and staff. This forced the effort to become ad hoc at best, bootlegged when possible with other funds, and harder to attract senior level user staff (Ph.D.s and postdocs).

Dr. Lawrence Goldberg, currently NSF senior engineering advisor, has provided excellent guidance for CNF from a little before NNUN formation to the present. His NSF perspective of CNF is included in these proceedings. He deserves great credit for the success of NNUN and NNIN evolutions and for the importance of these programs as part of the country's initiative in nanotechnology.

I mentioned earlier that directors come and go. However, that statement is a little too glib for all past directors and in particular for the immediate past director. No brief history of CNF would be complete without special mention of Professor Director Sandip Tiwari. Cornell and the national nanotechnology community owe him deep appreciation and gratitude for his leadership and stewardship of CNF, NNUN, and now NNIN. His management and knowledge of nanoscience and technology guided the successful transition from NNUN to NNIN, a continuation of the national "franchising" of CNF, while simultaneously moving CNF to new quarters! Under his tenure the 23-year old NRRFSS facility was literally buried only to rise bigger and better as CNF in much improved facilities within Duffield Hall. As one directly involved in creation of the old facility, I can say it served Cornell quite well, but good riddance! Balancing expectations with the hard realities of moving a functioning national user laboratory, with >700 active user projects, was a feat accomplished quite successfully by Dr. Tiwari and his CNF staff. Sandip pays tribute in the current issue of NanoMeter to the CNF staff for their exemplary effort at this critically important time in the history of CNF.

The installation and rapid attainment of full operational status of the new \$6 million JEOL JBX 9300 FS e-beam lithography system in late 2003 and early 2004 was a major milestone for CNF. This state-of-the-art system provides minimal feature-sizes approaching ~ 10 nm, a limit set by current polymeric resist resolution, not electron beam spot-size. In addition Sandip teaches in ECE, is the Founding Editor-in-Chief of IEEE Transactions on Nanotechnology, and he and his students are carrying out research that is at the cutting edge of nanoscale science and engineering. He came well prepared and when he stepped down as the Knight Director of CNF in 2006 he left CNF better prepared for prominent leadership in future nanoscale science and technology studies than ever before.

I personally wish Associate Professor George Malliaras, the current Lester B. Knight Director of CNF, and Director of Operations Don Tennant continued good success at CNF.

They both bring outstanding accomplishments and unique experiences to their new leadership positions at CNF. May they also have the opportunity to write about and document in thirty years (2037) an even greater record of accomplishments for CNF's 60th Anniversary celebration.

Conclusion

In closing temporarily this continuing history of CNF on its 30th Anniversary, it is noteworthy that nanoscale science and technology and Cornell University have become synonymous, and the nation is the better for it. As NRRFSS/NNF/CNF was evolving, Cornell administration and faculty were hard at work extending Cornell's research and resources into areas catalyzed, in part by the success of the facility, which include the Center for Nanoscale Systems (CNS) and Nanobiotechnology Center (NBTC), and culminating more recently with the prestigious award of the Kavli Institute at Cornell for Nanoscale Science.

We are addressing the Future of Nanotechnology today. Nanotechnology is an all-encompassing term. To me it includes both the top-down approach of adding and subtracting material through surface masking as well as the bottom-up approach of chemical self-assembly of materials, and combinations of the two approaches.

I believe nanotechnology is the future as the great enabler for many new discoveries in the physical and biological sciences and engineering. These discoveries will offer immense economic and social benefits. I would like to believe we will be as wise in our use of these discoveries, as nanotechnology will be proficient in producing them.

I wish to express my sincere appreciation to Melanie-Claire Mallison and Gabriel Terrizzi for their comments, suggestions and substantial data input for this ongoing history of CNF.

Appendix A. List of NRRFSS, NNF, and CNF Staff Members

Appendix B. List of Nellie Yeh-Poh Lin Whetten Award Winners

Appendix C. Chronological List of NRRFSS, NNF, and CNF Directors

Appendix D. Chronological List of NSF Program Directors

Reflecting on 30 Years of NSF Investment in Cornell's National User Facility Leading to the National Nanotechnology Infrastructure Network

Lawrence Goldberg

Senior Engineering Advisor
Division of Electrical and
Communications Systems
National Science Foundation

As we come to the 30th anniversary of the Cornell NanoScale Science & Technology Facility, we see a vibrant enterprise that has surpassed its original concept and evolved into a recognized world leader. There are users of the Cornell Facility everywhere who speak with fondness of the research that was enabled and of the education that was received through its openness to creative ideas and individuals. The National Science Foundation is very proud to have played a continuing role in this success.

In 1977, NSF established the National Research and Resource Facility for Submicron Structures at Cornell University under funding by the predecessor of the Electrical, Communications and Cyber Systems Division, Directorate for Engineering. The purpose of this single user facility was to serve the nation's academic and other researchers, from diverse fields such as micro-electronics, micromechanics, physics, biology, and optics, who found it beneficial to their research and education efforts to create structures with feature dimensions that could be substantially smaller than a micrometer. Cornell renamed the facility as the National Nanofabrication Facility in its renewal request in 1987, which was funded for an additional five years.

In 1993, the Directorates for Engineering and for Mathematical and Physical Sciences, with participation by the Directorate for Biological Sciences, issued a competitive solicitation for an integrated network of nanofabrication user facilities to succeed the single Cornell facility. As brought out in expert workshops, the demand for nanofabrication services by researchers was increasing at a rapid rate across a broad spectrum of disciplines, driven by the access nanostructures provided to new physical phenomena, devices, measurements, and experimental techniques. The solicitation stated that it was "the vision of the Foundation that the individual facilities comprising the network will work not as independent entities competing for limited resources, but rather as elements of a cooperative, integrated user facility system that seeks funding from government and industry for the common good of the network users, and allocates resources in a manner that best benefits the user community."

The network was established as the National Nanofabrication Users Network (NNUN) in 1994 by a team of five universities - Cornell University, Stanford University, Howard University, Pennsylvania State University, and the University of California at Santa Barbara. The award was under five-year cooperative agreements to the lead universities, Cornell and Stanford. In 1998, NNUN was

renewed for a final five-year period. The Directorate for Computer and Information Science and Engineering became the fourth Directorate participating in funding. NNUN had become an important investment in supporting the national infrastructure and education needs in nanoscience, engineering, and technology. The network's efforts expanded with increasing resources in fields of biology and chemistry during this period and served a steadily increasing number of users, including postdocs, graduate and undergraduate students, and many start-ups and small companies.

The network concept evolved further with the competitive solicitation in 2003 for the National Nanotechnology Infrastructure Network (NNIN). All of NSF's research and education Directorates were now participating in funding, including the Directorates for Geosciences, for Social, Behavior and Economic Sciences, and for Education and Human Resources. NNIN represented a major infrastructure investment by NSF under its Priority Area of Nanoscale Science and Engineering, intended to support the grand challenges and emerging new areas in nanotechnology then arising, in great degree, by the significant national resources being invested through the National Nanotechnology Initiative. The NSF vision for NNIN was that of an integrated national network of user facilities, diverse both in capabilities and research areas served, as well as in geographic locations. NNIN would provide researchers across the nation with access, both on-site and remotely, to leading-edge fabrication and characterization tools, instruments, and staff expertise to support nanoscale science and engineering research across all domains and to stimulate technological innovation. NNIN was also intended to develop and maintain advanced research infrastructure, contribute to the education and training of a new workforce skilled in nanotechnology and the latest laboratory techniques, conduct educational and knowledge outreach to the science and engineering communities, explore the societal and ethical implications of nanotechnology, and enhance the nation's cyberinfrastructure through extensive use of web-based shared resources, computational tools, and remote experimentation.

Following a rigorous competition among three major teams, the NNIN was awarded in 2004 to Cornell University as lead institution for a network of 13 university sites that included Georgia Institute of Technology, Harvard University, Howard University, North Carolina State University, Pennsylvania State University, Stanford University, University of California at Santa Barbara, University of Michigan, University of Minnesota, University of New Mexico, University of Texas at Austin, and University of Washington. The broad scope of NNIN coverage includes areas of physics, chemistry, materials, mechanical systems, geosciences, biology, life sciences, electronics, optics, molecular synthesis, molecular scale devices, and others, with the instrumentation and

capabilities for fabrication, synthesis, characterization, design, simulation and integration. Each of the network sites has exceptional technical strengths and expertise in at least one, and typically several, of these areas, supported by strong local research programs, a commitment to the principles of openness and flexibility as user facilities, strong internal support, capacity for growth to address emerging needs, and geographical diversity. NNIN has developed extensive education and outreach activities, including a highly effective network-wide Research for Undergraduates program, and a comprehensive effort to study societal and ethical implications of nanotechnology. Now into its fourth year of activity, NNIN's steadily increasing number of external users from diverse fields is underpinning the original premise of these national facilities.

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2007 CNF
30th Anniversary Celebration
Speaker Abstracts
&
Biographies



Edward Wolf

Professor Emeritus
ECE
Cornell University

Dr. Edward Wolf is professor emeritus since 1991, School of Electrical and Computer Engineering, Cornell University, and was the first director of what is now the Cornell NanoScale Science and Technology Facility (CNF) from 1978-88. Dr. Wolf received his Ph.D. in physical chemistry from Iowa State University and did postdoctoral studies at Princeton University. Prior to joining Cornell University, he spent fifteen years in aerospace R&D, and received the IEEE Fellow award for “contributions to scanning electron beam diagnostics and microfabrication techniques” as a Hughes Aircraft Corporation Senior Scientist at Hughes Research Laboratories, Malibu, CA. At Cornell Prof. Wolf’s research focused mainly on scanning electron beam lithography and chemically assisted ion beam and reactive ion etching. Dr. Wolf is the co-inventor of the gene gun and co-founder of Biolistics, Inc., which developed the Biolistics gene gun and associated processes for genetic transformation. Biolistics, Inc., sold its gene gun technology rights to DuPont in 1990. There are two gene guns on permanent display at the Smithsonian Institution, Washington, DC, and one in use at EPCOT Research in Orlando, FL. Dr. Wolf served eight years on the board of directors of the Cornell Research Foundation, the patent and licensing arm of Cornell University, and was the founding director of the Cornell Office for Technology Access and Business Assistance during 1995-96. Dr. Wolf also served eleven years on the board of directors, Phytion, Inc., a privately held company, which commercialized its proprietary plant cell fermentation technology in conjunction with Bristol-Myers-Squibb to produce the anticancer drug TAXOL®. He was associated with the Cayuga Venture Fund, Ithaca, NY, from its inception in 1995 to 2007, first as a member then as an advisory board member. Dr. Wolf serves on the board of directors, Novelx, Inc., a California startup working on miniaturized electron beam systems. Dr. Wolf has authored or co-authored more than two hundred seventy journal and conference papers, two book chapters, and has been awarded ten patents.

Notes:



Lawrence Goldberg

Senior Engineering Advisor
Division of Electrical and
Communications Systems
National Science Foundation

Dr. Lawrence Goldberg was born in St. Louis, Missouri. He received his B.S. degree in Engineering Physics from Washington University in 1961, and his Ph.D. degree in Solid State Physics from Cornell University in 1966. From 1966-67, he spent a postdoctoral year as research assistant at the Physikalisches Institut, Universität Frankfurt, Germany. From 1967-1985, he was with the Naval Research Laboratory as research physicist in the Optical Sciences Division. During 1976-1977, he was on sabbatical leave at Imperial College, London, England. Dr. Goldberg’s research interests have been in lasers, nonlinear optics, optical parametric devices, ultrashort pulse lasers and spectroscopy, liquid crystals, and radiation defects in crystals.

Dr. Goldberg came to the National Science Foundation in 1985 as Program Director for the Quantum Electronics, Waves, and Beams Program, in the Division of Electrical and Communications Systems, Directorate for Engineering. In the summer of 1989, he served as Acting Head of the NSF Office in Tokyo, Japan. His program responsibilities at NSF covered research areas of quantum electronics, optics, plasmas, and electromagnetics. He served also as Senior Staff Advisor and as Acting Division Director. In 1994, Dr. Goldberg was appointed Director of the Division of Electrical and Communications Systems and served until January 1998. Dr. Goldberg now holds the position of Senior Engineering Advisor in the Division of Electrical, Communications and Cyber Systems.

Dr. Goldberg served under appointment by the President’s Science Advisor as NSF member of the Joint Management Committee for the U.S.-Japan Joint Optoelectronics Project. He helped develop and coordinate the NSF-wide initiative in Optical Science and Engineering, the NSF/DoE Partnership in Basic Plasma Science and Engineering, and the NSF/NIH Scholar-in-Residence at NIH. He provided oversight for the National Nanofabrication Users Network (NNUN), and served five-years as chair of the NSF coordinating committee for the Integrative Graduate Education and Research Traineeship (IGERT) program.

Dr. Goldberg guided the competition and now provides oversight for the National Nanotechnology Infrastructure Network (NNIN). He also provides oversight for the NSF Science and Technology Center on Nanobiotechnology at Cornell University, and the NSF/DARPA Photonics Technology Access Program (PTAP). Dr. Goldberg coordinates joint activities on nanoelectronics with the Semiconductor Research Corporation and the Silicon Industry Association, conducted under NSF’s priority area of Nanoscale Science

and Engineering. He also coordinates the Major Research Instrumentation program for the Engineering Directorate.

Dr. Goldberg served in early 2005 as U.S. Embassy Science Fellow in Chisinau, Moldova, where he worked in close cooperation in an advisory role with the President of the Academy of Sciences of Moldova. He has since participated in government-level science studies in Ukraine, Kazakhstan, and Romania.

Dr. Goldberg is Fellow of the Optical Society of America, and Fellow of the Institute of Electrical and Electronic Engineers.

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George Malliaras

Lester B. Knight Director of the
Cornell NanoScale Facility
Cornell University

George Malliaras is the *Lester B. Knight* Director of the Cornell NanoScale Facility, and an Associate Professor in the Department of Materials Science and Engineering at Cornell University. Prof. Malliaras received a BS in Physics from the Aristotle University (Greece), and a PhD, *cum laude*, in Mathematics and Physical Sciences from the University of Groningen (the Netherlands). His thesis work was on photorefractivity in polymers. He then did a one year postdoc at the University of Groningen and a two year postdoc at the IBM Almaden Research Center (California), working on organic light emitting diodes. He joined Cornell University in 1998 as an Assistant Professor in the Department of Materials Science and Engineering. Prof. Malliaras is the recipient of the NSF Young Investigator Award, the DuPont Young Professor Grant, and a Cornell College of Engineering Teaching Award. He serves on the board of directors of *Infotonics*, a MEMS fabrication facility designed to provide a rapid pathway to commercialization, is the chairman of the editorial board of the *Journal of Materials Chemistry*, and serves on the editorial board of *Sensors*. He has also been an editor for the *Japanese Journal of Applied Physics*. Prof. Malliaras' research interests span several aspects of organic electronics, including structure and morphology of organic thin films, their processing and patterning, charge transport and injection in organic semiconductors, device physics, and applications of organic devices in biosensors.

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PLENARY



Stephen Kresovich is a Professor in the Departments of Plant Breeding and Genetics and Plant Biology. During his tenure at Cornell, Dr. Kresovich has served as the Director of the Institute for Genomic Diversity, the Director of the Institute for Biotechnology and Life Sciences Technologies, and the Associate Vice Provost for Life Sciences. In 2005,

Dr. Kresovich became the Vice Provost for Life Sciences. In this position he is responsible to promote and administer the New Life Sciences Initiative, including the hiring of new faculty, planning for new buildings, developing shared core research facilities, and supporting educational and training activities based on Cornell's comprehensive investments in the life sciences.

Dr. Kresovich received his A.B. in biology from Washington and Jefferson College, M.S. in agronomy at Texas A&M University, and Ph.D. in crop physiology and genetics from The Ohio State University in 1982. Following graduation, he conducted research in crop breeding and biotechnology at Battelle Memorial Institute and Texas A&M University. Prior to joining the Cornell faculty in 1998, he served for eleven years as Laboratory Director at two U.S. National Genetic Resources Program genebanks in New York (1987-93) then in Georgia (1993-98). Dr. Kresovich's research focuses on conservation genetics and improvement of crop plants including maize, sorghum, and pearl millet. Dr. Kresovich is a Fellow of the American Association for the Advancement of Science and the Crop Science Society of America. Since 1997, he has served as the U.S. Agency for International Development's Scientific Liaison Officer for Genetic Resources Conservation for the U.N.-supported International Agricultural Research Centers. In 2001, Dr. Kresovich was appointed to the Executive Committee of the New York State Biodiversity Research Institute.

Dr. Kresovich's research objectives are: (1) to identify regions of the sorghum and maize genomes which have been fixed through evolution, domestication, or crop improvement and associate these selective sweeps with useful types and traits, (2) to characterize and understand the relationship between DNA sequence variation and desirable phenotype, (3) to identify both conserved sequences across grass/grain families and genera and rapidly evolving sequences between species and individuals to predict gene diversity and function, (4) to characterize molecular diversity of sorghum and maize in natural populations, landraces, and elite germplasm, and (5) to develop and test strategies to efficiently discover, conserve, and use variation in natural populations and genebank collections by integrating current advances in genomics, bioinformatics, and plant genetics/breeding. In support of Cornell University's commitment to global conservation and agricultural initiatives, he serves as Director of the Institute for Genomic Diversity.

nanoTech



Donald Tennant is the newly appointed Director of Operations at the Cornell Nanoscale Science and Technology Facility leaving a 27 year career at Lucent Bell Labs. At Bell Labs Don was a Distinguished Member of Technical Staff where he managed the Advanced Lithography Group. Since 1979 he worked at Bell in the area

of high resolution electron beam lithography and related nanostructure technology. His work has had significant impact on a wide range of disciplines, including: soft x-ray imaging and extreme ultraviolet lithography (EUVL), high precision grating production for DWDM (dense wavelength division multiplexing), and gate technology for both high performance circuit applications and the exploration of the practical limits of silicon technology. His collaborative efforts with SUNY Stony Brook and Brookhaven National Laboratories have resulted in important advances in the field of x-ray optics and microscopy. He has authored or co-authored over 200 articles in these fields, organized major international conferences on the subject, presented numerous invited technical talks and posters, and has been awarded 10 U.S. patents. He currently serves on the Advisory Committee and is the Financial Trustee for the International Conference of Electron, Ion, and Photon Beams and Nanotechnology (EIPBN). He is a Past Chair of the Nanometer Science and Technology Division of the AVS and has served as a panelist for the National Research Council of the National Academies.

nanoMed



Harold Craighead received his Bachelor of Science Degree in Physics, with High Honors, from the University of Maryland, College Park in 1974. He received his Ph.D. in Physics from Cornell University in 1980. His thesis work involved an experimental study of metal nanoparticles. From 1979 until 1984 he was a Member of the Technical

Staff in the Device Physics Research Department at Bell Laboratories. From 1984 until 1989 he was Research Manager of the Quantum Structures Research Group at Bellcore. Dr. Craighead joined the faculty of Cornell University as a Professor in the School of Applied and Engineering Physics in 1989. From 1989 until 1995 he was Director of the National Nanofabrication Facility at Cornell University. Dr. Craighead was Director of the School of Applied and Engineering Physics from 1998 to 2000 and Director of the Nanobiotechnology Center from 2000 to 2001. He served as Interim Dean of the College of Engineering from 2001 to 2002. He served as co-Director of the Nanobiotechnology Center from 2002-2006, and currently serves as the Director of the Nanobiotechnology Center. He is an elected member of the National Academy of Engineering.

nano&Us



Ronald Kline received a Ph.D. in the history of science from the University of Wisconsin--Madison in 1983. He was director of the IEEE's Center for the History of Electrical Engineering from 1984 to 1987, joining Cornell University in 1987. In 2003, he was elected as the first Bovay Professor of the History and Ethics of Professional

Engineering at Cornell. He holds a joint appointment between the School of Electrical and Computer Engineering and the Science and Technology Studies Department in the Arts College. Kline has served as president of the IEEE Society on Social Implications of Technology and editor of the IEEE Technology and Society Magazine. He is currently an advisory editor for the journals *Social Studies of Science and Technology and Culture*, and is on the editorial committee of the IEEE Society on Social Implications of Technology. He is the author of several articles on the history and ethics of engineering and technology and two books, *Steinmetz: Engineer and Socialist* (1992), and *Consumers in the Country: Technology and Social Change in Rural America* (2000). He is currently writing a book on the history of cybernetics, information theory, and discourses about an Information Age from the 1945 to the present.

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nano&Us Panel Discussion



Stephen Hilgartner is an associate professor in the Department of Science & Technology Studies. His research has centered on the social dimensions and politics of contemporary and emerging science and technology. Much of his work has focused on struggles over the credibility of knowledge and over the authority of expertise. He has examined

these themes in a number of situations in which scientific knowledge is implicated in contesting and maintaining social order, including studies of science advice, risk disputes, property formation, and public knowledge. Hilgartner's book *Science on Stage: Expert Advice as Public Drama* which examines how the authority of scientific advisory bodies is produced, contested, and maintained won the Carson Prize from the Society for Social Studies of Science in 2002. Much of Hilgartner's work examines these questions in the areas of biology and medicine, especially in the area of genome research. He has also contributed to the literature on the construction of social problems. Hilgartner teaches a variety of courses that address the theme of contentious knowledge. These include *Science in the American Polity; Knowledge, Technology, and Property; and The New Life Sciences: Emerging Technology, Emerging Politics*.

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Manufacturing at the Nanoscale

There is currently a tremendous business incentive to invent new electronic, photonic and mechanical devices and circuits that will have dimensions of the order of nanometers. In addition, new fabrication techniques will be required that can inexpensively produce and connect these devices in vast quantities. The challenges are equivalent to those faced by the inventors of both the transistor and the integrated circuit, who replaced the existing vacuum-tube and wiring technologies with solid-state switches and lithographic fabrication, respectively. In order to satisfy both requirements simultaneously, we have assembled a trans-disciplinary team of chemists, physicists, engineers, computer scientists and mathematicians at HP Labs.

Two complementary research areas relevant to future nanocomputing systems are currently under investigation: (1) nano-scale switching devices and circuits for both electrons and photons, and (2) the development of new and inexpensive fabrication techniques. Our approach for the construction of electro-photonic circuits involves the explicit incorporation of defect tolerance, which is the capability to operate perfectly even in the presence of manufacturing mistakes in the circuit, into the design of the system. This prerequisite arises from the realization that it is prohibitively expensive to fabricate a perfect network of billions of nanoscale components. However, by introducing the appropriate amount of redundancy and utilizing concepts from coding theory and reconfiguration, arbitrary complexity can be programmed into a highly regular structure and at the same time any defects can be avoided.

Our research group has recently demonstrated the ability to fabricate electronic switches with sub-viral length scales (e.g. ~ 15 nm) and to build photonic modulators at 1550 nm wavelength based on ‘left-handed’ metamaterials using the technique of nano-imprint lithography. We are exploring new concepts for nanoscale circuits with the capability to perform signal restoration and inversion (required for universal computing) without the need for transistors. This has led us to discover an entirely new logic family based on the Boolean “Implication” operation that is specifically suited to the properties of nanoscale switches and crossbars. We have built and demonstrated laboratory prototype memory and logic circuits based on these new ideas that exceed the density of today’s semiconductor circuits by one to two orders of magnitude, and we are investigating computing systems with both optical and photonic components that should enable dramatic improvements in performance over all electronic systems.

I will describe how fundamental research in a corporate research laboratory can be a strategic asset for the company, and how it is possible to mix curiosity-driven discovery with invention by the proper choice of research area.

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R. Stanley Williams

HP Senior Fellow
Hewlett-Packard Laboratories

Figure 1. An Atomic Force Microscope topograph of a section of a 16 kbit crossbar electronic memory with a 17 nm half-pitch (wire and space widths) fabricated at HP Labs using imprint lithography.

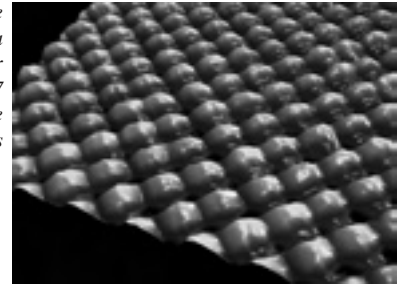
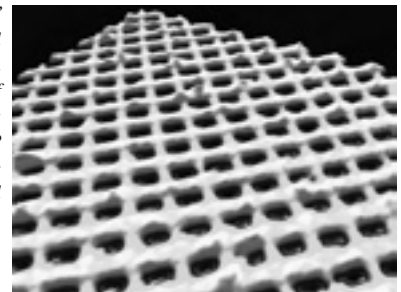


Figure 2. A ‘left-handed’ fishnet geometry metamaterial (a photonic modulator) with a resonance wavelength of 1550 nm fabricated using imprint lithography at HP Labs. The smallest feature size in this artificial material is 30 nm.



R. Stanley Williams is Senior Fellow at Hewlett-Packard Laboratories and founding Director of the Quantum Science Research (QSR) group. He received a B.A. degree in Chemical Physics in 1974 from Rice University and his Ph.D. in Physical Chemistry from U. C. Berkeley in 1978. He was a faculty member (Assistant, Associate and Full Professor) of the Chemistry Department at UCLA from 1980 – 1995. His primary scientific research during the past twenty years has been in the areas of solid-state chemistry and physics. His awards for scientific and academic achievement include the 2000 Julius Springer Award for Applied Physics, the 2000 Feynman Prize in Nanotechnology, and the 2004 Birnbaum Prize. He was named to the inaugural Scientific American 50 Top Technology leaders in 2002, and the molecular electronics program he leads was named the Technology of the Year for 2002 by Industry Week magazine. He has been awarded 41 US patents and has published 262 papers in reviewed scientific journals.

Notes:

Nanoscale Devices for Medical Diagnostics

James Heath

Elizabeth W. Gilloon Professor of Chemistry
Caltech Chemistry

The development of robust methods for integrating high-performance semiconductors on flexible plastics could enable exciting avenues in fundamental research and novel applications. One area of vital relevance is chemical and biological sensing, which if implemented on biocompatible substrates, could yield breakthroughs in implantable or wearable monitoring systems. Semiconducting nanowires (and nanotubes) are particularly sensitive chemical sensors because of their high surface-to-volume ratios. I will discuss a scalable and parallel process for transferring hundreds of pre-aligned silicon nanowires onto plastic to yield highly ordered films for low-power sensor chips. Combined with the appropriate surface chemistries they can be used to construct a “nano-electronic nose” library, which can distinguish volatile organic compounds via distributed responses. I will also discuss the quantitative, real-time detection of single-stranded oligonucleotides with silicon nanowires (SiNWs) in physiologically relevant electrolyte solutions. A model for the detection of analyte by SiNW sensors was developed and utilized to extract DNA-binding kinetic parameters. The implication is that SiNWs can be utilized to quantitate the solution-phase concentration of biomolecules at low concentrations. This work also demonstrates the importance of surface chemistry for optimizing biomolecular sensing with silicon nanowires.

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James Heath is the Elizabeth W. Gilloon Professor and Professor of Chemistry at Caltech, and Professor of Molecular & Medical Pharmacology at UCLA, and Director of the National Cancer Institutes NSB Cancer Center. Heath received a B.Sc. degree in 1984 (Baylor) and his Ph.D. in Chemistry (Rice) in 1988 where he was the principal student involved in the Nobel Prize-winning discovery of C_{60} and the fullerenes. Heath was a Miller Fellow at UC Berkeley from 1988-91, and on the Technical Staff at IBM Watson Labs from 1991-93. In 1994 he joined the faculty at UCLA. He founded the California NanoSystems Institute in 2000 and served as its Director until moving to Caltech. Heath has investigated quantum phase transitions, and he has developed architectures, devices, and circuits for molecular electronics. His group has recently been applying their advances on nanoelectronics circuitry toward addressing problems in cancer. He has received a number of awards, including a Public Service Commendation from Governor Grey Davis, the Sackler Prize, the Spiers Medal, the Feynman Prize, the Jules Springer Prize, and the Arthur K. Doolittle Award. He has founded or co-founded several companies, including NanoSys, MTI, MoB, and Homestead Clinical, and he serves on the board of a number of organizations, including the Board of Scientific Advisors of the National Cancer Institute.

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Constituting the NanoScale: Lessons from the 20th Century

Sheila Jasanoff

Pforzheimer Professor of Science and Technology Studies
Kennedy School, Harvard University



Sheila Jasanoff is Pforzheimer Professor of Science and Technology Studies at Harvard University's John F. Kennedy School of Government, where she directs the Program on Science, Technology and Society. She is also affiliated with the Department of the History of Science, member of the Board of Tutors in Environmental Science and Public Policy, and visiting professor at Harvard Law School. Before joining Harvard, she was Professor of Science Policy and Law and founding chair of the Department of Science and Technology Studies at Cornell University. She has been Leverhulme Visiting Professor at the University of Cambridge, Fellow at the Berlin Institute for Advanced Study, and Karl Deutsch Guest Professor at the Science Center Berlin.

Technological innovation can be seen as a process of increasingly persuasive story-telling, about materials, about machines and their components, and about the human actors who will use and benefit from them. For modern technologies, that story-telling engages as much with society's capacity to control the unwanted results of innovation as with technology's transformative potential. Throughout the 20th century, much academic and administrative ingenuity was invested in assessing the adverse consequences of technology and seeking to prevent or mitigate them. Many methods resulted: cost-benefit analysis, technology assessment, risk assessment, environmental impact assessment, scenario and model building, and ethical analysis, among others. None proved failsafe. Defects in these approaches have led some to call for a moratorium on potentially revolutionary advances, such as in nanotechnology. Others decry restraint as unwise, unwarranted, and unduly pessimistic. In this talk, I draw on theories from science and technology studies to side with the proponents of moving ahead, but I suggest that technological innovation should be regarded as a form of governance whose legitimacy depends on political as well as material and technical design elements. Drawing on instructive examples from the 20th century – nuclear power, organic chemicals, biotechnology – I argue for two major political design elements: first, a space for “ontological politics,” that is, for debate about the entities we bring into the world; and, second, attention to “technologies of humility,” grounded in memory and experience, to complement expert-dominated, high-tech approaches to prediction.

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Professor Jasanoff's longstanding research interests center on the interactions of law, science, and politics in democratic societies. She is particularly concerned with the construction of public reason in various cultural contexts, and with the role of science and technology in globalization. Specific areas of work include science and the courts; environmental regulation and risk management; comparative public policy; social studies of science and technology; and science and technology policy. She has published more than 85 articles and book chapters on these topics and has authored or edited numerous books, including Controlling Chemicals: The Politics of Regulation in Europe and the United States (1985; with R. Brickman and T. Ilgen), Risk Management and Political Culture (1985), The Fifth Branch: Science Advisers as Policymakers (1990), and Science at the Bar: Law, Science and Technology in America (1995), which received the Don K. Price award of the American Political Science Association. Her most recent publications include an edited volume, States of Knowledge: The Co-Production of Science and Social Order (2004), and Designs on Nature: Science and Democracy in Europe and the United States (2005).

Jasanoff has served on the Board of Directors of the American Association for the Advancement of Science and as President of the Society for Social Studies of Science, as well as on numerous scientific advisory committees in the United States, Britain, Austria, and Germany. Currently, she is a member of the National Academy of Science's standing committee on Social Science Evidence for Use. She holds AB, JD, and PhD degrees from Harvard University and an honorary doctorate from the University of Twente.

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Carbon Nanotubes: Electronics and Optoelectronics in One-Dimension

Phaedon Avouris

IBM Fellow and manager of Nanometer Scale
Science and Technology
IBM T. J. Watson Research Center

As the scaling of silicon-based devices is approaching its limits, intense efforts are made to find new device platforms. One of the most promising systems is carbon nanotubes (CNTs). Although a variety of different electronic devices based on CNTs have been demonstrated, most of the emphasis has been placed on CNT field-effect transistors (CNTFETs). In these devices a semiconducting CNT molecule replaces silicon as the transistor channel. The resulting devices have superior characteristics, but also pose a set of new physics and technology challenges. In my talk I will discuss these issues and demonstrate solutions that allow the fabrication of not only individual devices with excellent characteristics, but also more complex integrated circuits, such as ring oscillators, based on a single CNT molecule. [1]

In our effort on CNT optoelectronics we are mostly interested in the electrical production of excitations in CNTs. This we accomplish in two different ways. In one mode, excitations are generated by independently injecting electrons and holes in the channel of an ambipolar CNT field-effect transistor (FET). [2,3] Radiative e-h recombination in such a system produces single nanotube molecule light sources. [2] In a different approach we take advantage of the strong e-h interactions and weak electron-phonon interaction in CNTs that allows for efficient intra-CNT impact excitation by hot carriers under unipolar transport conditions. [4,5] Our theoretical analysis shows that impact excitation rates are much higher in CNTs compared to 3D solids. [6] Examples of naturally occurring [5] and fabricated [4] structures that emit unipolar electroluminescence will be discussed. Finally, we will discuss the inverse process of light absorption generated currents (photoconductivity) and photovoltage in CNTs [7, 8] and their potential uses.

References

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- [2] J. A. Misewich, R. Martel, Ph. Avouris, et al. *Science* 300, 783 (2003).
- [3] M. Freitag, et al. *Phys. Rev. Lett.* 93, 076803 (2004).
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- [6] V. Perebeinos, Ph. Avouris, *Phys. Rev. B* 74, 121410(R) (2006).
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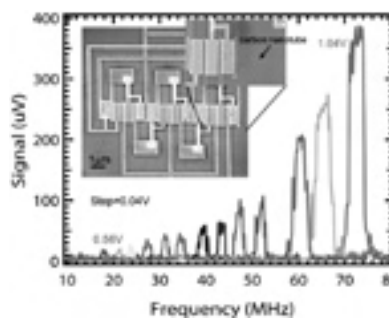
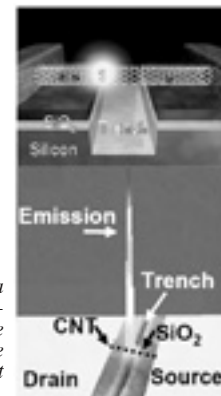


Figure 1. shows an electron microscope image of a ring-oscillator circuit based on a single carbon nanotube, as well as its output as a function of supply voltage.

Figure 2. shows on top a schematic of a "trenched" field-effect transistor and on the bottom an optical image of the trench and the associated light emission.



Phaedon Avouris is an IBM Fellow and manager of Nanometer Scale Science and Technology at the Research Division of IBM, T.J. Watson Research Center. He received his B.S. degree from the Aristotelian University in Greece, and his Ph.D. degree in Physical Chemistry from Michigan State University in 1974. After postdoctoral work at UCLA and AT&T Bell Laboratories, he joined the Research Division of IBM in 1978. He is also Adjunct Professor at Columbia University and the University of Illinois.

Over the years, his research has involved a wide variety of subjects ranging from laser spectroscopy, surface physics and chemistry, scanning tunneling microscopy, atom manipulation, to nanoelectronics. His current research is focused on experimental and theoretical studies of the electrical properties and transport mechanisms in carbon nanotubes, molecules and nanowires. The work includes the design, fabrication and study of model nanoelectronic devices and circuits.

Dr. Avouris has published over 350 scientific papers. He is a Fellow of the American Academy of Arts and Sciences, the American Physical Society, the Institute of Physics of the U.K., the Academy of Athens, the IBM Academy of Technology, the American Association for the Advancement of Science, American Vacuum Society and the New York Academy of Sciences. He has received several awards including the Irving Langmuir Prize (APS), the Medard W. Welch Award (AVS), the Feynman Prize for Molecular Nanotechnology (FI), the Nanoscience Prize (ACSIN), the Raper Award (IEEE), the Distinguished Alumnus Award (MSU), and a number of IBM Corporation "Outstanding Technical Achievement" awards. He serves in the Editorial Boards of seven journals and edits the Springer series on Nanoscience.

Utilizing Surface Enzyme Chemistry, Plasmons and Nanoparticles for Ultrasensitive Biosensing

Microarray biosensors have become an invaluable biotechnological tool for the rapid, multiplexed detection of surface bioaffinity interactions. For example, nucleic acid microarrays are currently used in the areas of genetic DNA testing, SNP genotyping and gene expression analysis. Many researchers are also interested in developing protein microarrays for application in the areas of proteomics and drug discovery, and the screening of multiple protein biomarkers in biological fluids with microarrays is a potentially powerful method for the diagnosis of diseases and the monitoring of subsequent therapeutic treatments.

In the last decade, the use of nanoscale metallic structures such as nanoparticles, nanorods, and ultrathin films have emerged as an attractive alternative to traditional fluorescence-based detection methods for the detection of biological molecules. The use of ultrathin gold or silver films in technique of surface plasmon resonance imaging (SPRI) is a particularly attractive method for monitoring multiplexed bioaffinity adsorption onto biopolymer microarrays.[1] SPRI detects changes in the local index of refraction upon adsorption at an interface; the use of inherent refractive index changes is a significant advantage in the analysis of biological samples, where the labeling of multiple biomarkers with fluorophores or radioactive tracers is often not possible. We have worked over the last ten years to improve the spectroscopic method of SPRI in terms of instrumentation, surface microarray fabrication, and the use of microfluidic formats for the multiplexed measurement of surface adsorption kinetics with microarrays.

A second set of techniques for biosensing with nanoscale metallic structures has been the use of the localized surface plasmon resonance (LSPR) in gold and silver nanoparticles, nanorods and even nanotriangles. Metallic nanoparticles can also be used in conjunction with SPRI and SPR diffraction methods for an even greater combined enhanced sensitivity; some of the combined methodologies we use will be described in this talk.[2]

A final methodology that has become essential in advanced surface bioaffinity sensing is the coupling a bioaffinity process to one or more surface enzymatic transformations.[3] Surface enzyme chemistry, which differs from the traditional enzymatic biosensing methods in that the substrate is a surface species and the enzyme is in solution, can be used to enhance sensitivity, selectivity and also to create unique biopolymer microarrays. The additional incorporation of DNA-coated gold nanoparticles into these enzymatically amplified methods can further increase the sensitivity of these bioaffinity measurements. Our most recent work has emphasized the use of nanoparticle enhanced surface enzyme chemistries and for the creation of ultrasensitive SPRI measurements of DNA and micro RNA down to just a few thousand molecules.

References

1. E. A. Smith, R. M. Corn, *Applied Spectroscopy*, 57 320A (2003).
2. S. Fang, H. J. Lee, A. W. Wark, R. M. Corn, *J. Am. Chem. Soc.*, 128 14044 (2006)
3. H. J. Lee, A. W. Wark, R. M. Corn, *Langmuir*, 22 5241 (2006).

Robert Corn

Professor of Chemistry
Department of Chemistry
University of California-Irvine

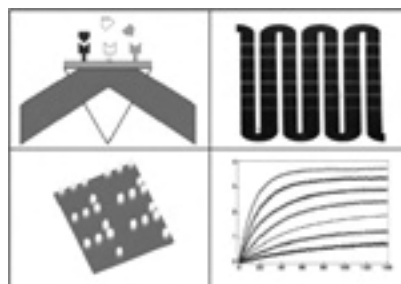


Figure 1. SPRI measurements of bioaffinity adsorption.

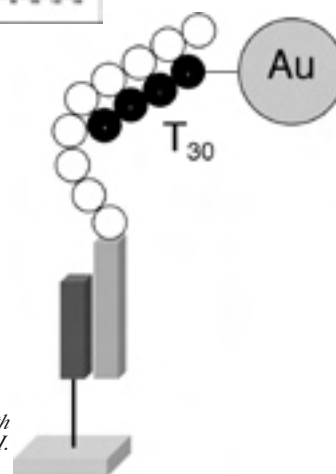
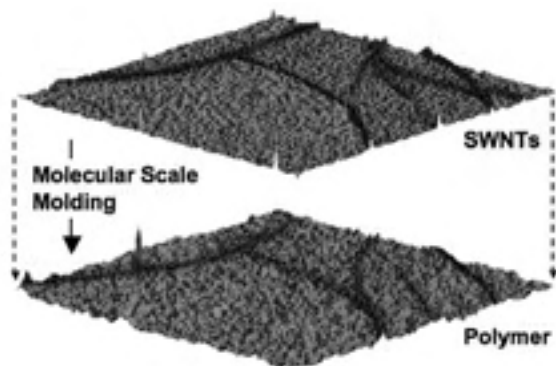


Figure 2. miRNA sensing with nanoparticle enhanced SPRI.



Robert Corn is a Professor in the Department of Chemistry at the University of California, Irvine. Prof. Corn is a leader in the development and application of surface-sensitive spectroscopic techniques such as surface plasmon resonance imaging, optical second harmonic generation, and polarization modulation Fourier transform infrared spectroscopy. His primary research interests include the study of biopolymer adsorption onto surfaces and the chemical modification of surfaces for the creation of ultrathin films and adsorption-based biosensors. After obtaining a Ph. D. in Physical Chemistry from the University of California, Berkeley, Prof. Corn came to the University of Wisconsin-Madison in 1985 and was an Analytical Chemistry Professor in the Department of Chemistry from 1985 to 2004. In July of 2004, Prof. Corn moved to the University of California, Irvine, where he is currently holds appointments in the Departments of Chemistry and Biomedical Engineering. Prof. Corn is also a co-founder of two biotechnology companies: GWC Technologies and GenTel BioSciences. Most recently, Prof. Corn is the recipient of the 2007 Pittcon Pittsburgh Spectroscopy Award and the 2007 ACS Division of Analytical Chemistry Award in Spectrochemical Analysis.

Approaches to Three Dimensional and Molecular Scale Nanofabrication



Progress in nanoscience and technology relies critically on the ability to build structures with nanometer dimensions. Established tools, which have their origins in the microelectronics industry, are spectacularly well suited to the applications for which they were principally designed. These methods have drawbacks, however, that limit their use in new fields of study: they require expensive facilities; they have difficulty forming features smaller than ~ 100 nm; they can pattern directly only narrow classes of specialized polymers; and they can only be applied, in a single step, over relatively small areas on ultraflat substrates. The last feature, which arises from a narrow depth of focus, also restricts their application to two dimensional (2D) patterning, unless processing intensive layer-by-layer strategies are used. These limitations create opportunities for new methods, ranging from adaptations of conceptually old techniques based on printing, molding and writing, to strategies that rely on bottom-up growth, self-assembly, phase separation and others.

This talk describes unconventional lithographic methods based on (i) advanced forms of soft nanoimprint lithography for 2D patterning with resolution that extends to molecular (~ 1 nm) length scales, and (ii) conformable phase mask optics for single step formation of fully three dimensional (3D) nanostructures. The first method relies on optimized polymers for molds and mold materials that, together, enable lithographic fidelity at the ~ 1 -2 nm scale, as demonstrated by the replication of relief structures defined by individual single walled carbon nanotubes with diameters down to ~ 0.7 nm. The use of this method to form alignment layers for liquid crystal devices illustrates a realistic application and a simple example of the broader notion of molded molecular structures for chemical and biological surface recognition.

The second method exploits an unusual class of optical element – an elastomeric, sub-wavelength phase mask – in a contact mode exposure geometry to generate 3D structures in photopolymers and other materials in a single patterning step. Aspects such as the self-imaging, Talbot effect optics of this approach, its capabilities for creating periodic, aperiodic and quasi-crystalline 3D nanostructures and selected applications in microfluidics, laser fusion targets and photonic crystals will be discussed.

John Rogers

Founder Professor of Engineering
University of Illinois at Urbana/Champaign

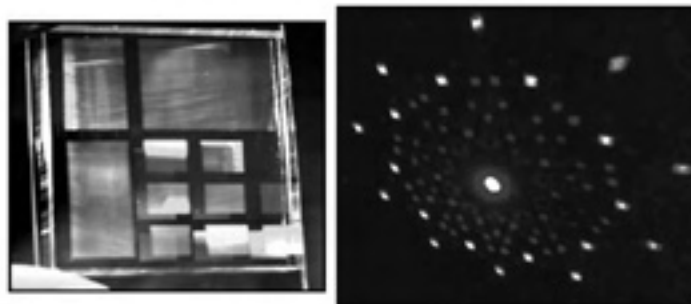


John Rogers, obtained BA and BS degrees in chemistry and in physics from the University of Texas, Austin, in 1989. From MIT, he received SM degrees in physics and in chemistry in 1992 and the PhD degree in physical chemistry in 1995. From 1995 to 1997, Rogers was a Junior Fellow in the Harvard University Society of Fellows. During this time he also served as a

Director for Active Impulse Systems, a company based on his PhD research that he co-founded in 1995 and which was acquired by a large company in 1998. He joined Bell Laboratories as a Member of Technical Staff in the Condensed Matter Physics Research Department in 1997, and served as Director of this department from 2000-2002. He is currently Founder Professor of Engineering at University of Illinois at Urbana/Champaign, with appointments in the Departments of Materials Science and Engineering, Electrical and Computer Engineering, Mechanical Science and Engineering and Chemistry.

Rogers research includes fundamental and applied aspects of nano and molecular scale fabrication, materials and patterning techniques for large area electronics and unusual photonic systems. He has published more than 175 papers, and has ~ 60 patents, more than 30 of which are licensed or in active use. His research has been recognized with many awards including the Harvard University Robert B. Woodward Scholar Award (2001), American Chemical Society's Team Innovation Award (2002), and the Xerox Distinguished Lecturer Award (2006). He is a Fellow of the American Physical Society, and serves on several Editorial Boards, including those for Applied Physics Letters, Journal of Applied Physics and Nano Letters. Most recently, he received the 2007 Daniel Drucker Eminent Faculty Award, the highest honor that the University of Illinois College of Engineering bestows on one of its faculty, for achievement in research and teaching.

Quasi-Crystal Phase Mask Optics



Nanostructure Engineering A Path to Discovery, Innovation, and Commercialization

Stephen Chou

Joseph C. Elgin Professor of Electrical Engineering
NanoStructure Laboratory, Department of Electrical Engineering
Princeton University

Advances in our ability to engineer nanostructures are creating a unique path to discovery and innovation in science and technology. This is because when nanostructures become smaller than a fundamental physical length scale, conventional theory may no longer apply and new phenomena emerge. This will not only deepen our knowledge, but also lead to better or revolutionary products in multiple areas, ranging from consumer products to medicine. The talk will first illustrate some intriguing phenomena manifested in nanostructures in the areas of electronics, optics, magnetic, biotech and materials, when the device sizes are smaller than the electron wavelength, optical wavelength, magnetic domain wall size, DNA persistent length, single-crystal critical size, and defect diffusion length. The talk then will address a grand challenge essential to the success of nanotechnology and its commercialization: high-throughput and low-cost nanopatternings (i.e., nanomanufacturing). Two different approaches will be presented: nanoimprint lithography (NIL), which has demonstrated the fabrication of sub-5 nm feature-size 3D patterning over large areas, and guided self-assembly (GSA), in particular, those that have well-ordered self-assembly over entire wafers, such as lithographically-induced self-assembly (LISA) and shear-force guided self-assembly.



Stephen Chou, Joseph C. Elgin Professor of Engineering and the head of the NanoStructure Laboratory at Princeton University, is a world leader, pioneer, and inventor in a broad range of nanotechnologies. Dr. Chou received his PhD from MIT in 1986. He was a Research Associate and Acting Assistant Professor at Stanford University (1986--1989), and a faculty member at the University of Minnesota (1989-1991, Assistant Prof, 1991-1994, Associate Prof, and 1994-1997 Full Prof), and joined Princeton University in 1997. As an entrepreneur, Dr. Chou founded Nanonex Corp. (1999) and NanoOpto Corp. (2000). Presently, Professor Chou leads a group of 14 researchers in exploration of innovative nanofabrication technologies and nanodevices in multiple disciplines. He is a member of National Academy of Engineering.

Dr. Chou's pioneering research and inventions in a broad spectrum of nanotechnologies and nanodevices has helped shape new paths in the fields of nanofabrication, nanoscale electronics, optoelectronics, magnetics, biotechnology and materials. Dr. Chou's graduate work used X-ray lithography

to scale MOSFETs to the 60 nm range, and since 1985 he has demonstrated various ultra-small MOSFETs, quantum devices, and single electron transistors. In early 1990's, he began pioneering work in exploring sub-wavelength optical elements (SOEs) –a new class of optical devices suited for on-chip integration, and in bringing nanofabrication into magnetic data storage media. He originated quantized magnetic disks (QMDs) – a new paradigm in magnetic data storage. In 1995, he pioneered his best-known work, nanoimprint lithography (NIL), a revolutionary nanoscale patterning method that allows sub-10 nm patterning over large areas with high throughput and low cost. And he has been a key developer of NIL. Dr. Chou is also a key inventor of lithographically induced self-assembly (LISA) and laser-assisted direct imprint (LADI). He had explored innovative applications of NIL, LISA and LADI in a wide range of disciplines, from electronics and optics to magnetics, biotech, and materials.

Dr. Chou's inventions and pioneer work have brought significant impacts to industry. Nanoimprint lithography is regarded as one of the "10 emerging technologies that will change the world." (MIT Technology Review); is selected as a next generation lithography for semiconductor ICs; and is becoming an enabling manufacturing platform for multiple multi-billion-dollar industries ranging from semiconductor ICs, magnetic data storage, displays, optics, biotech to nanomaterials. Furthermore, SOEs and QMDs are being developed by industries aggressively as a future of integrated optics and magnetic data storage.

Dr. Chou received 2004 IEEE Brunetti Award "for the invention and development of tools for nanoscale patterning, especially nanoimprint lithography, and for the scaling of devices into new physical regimes." Other awards he received include IEEE Fellow, Packard Fellow, an Inductee of New Jersey High Technology Hall of Fame, Pioneer Award of Nanoimprint and Nanoprint Technology, the Joseph C. Elgin Professorship, the McKnight-Land Grant Professorship, the George Taylor Distinguished Research Award at the University of Minnesota, DARPA ULTRA program Significant Technical Achievement Award, and three best paper awards. Dr. Chou has published more than 280 papers, has given over 130 invited presentations at conferences and workshops, and holds 19 patents and over 40 patent applications. He has served on the committees of a wide range of international conferences.

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A Tiny Revolution: New Tools for Synthetic Biology

Gregory Timp

Professor of Electrical Engineering
University of Illinois

A living cell perceives the microenvironment around it and adroitly respond using a sprawling network of proteins. A cell senses the microenvironment through protein receptors in the plasma membrane, and then transduces the signal, converting it to special proteins that can bind to DNA and regulate the rate at which specific genes are read. The genes are then transcribed into mRNA, which is eventually translated into appropriate proteins that respond in turn to the environment. Errors in the signal processing within this protein network have been implicated in autoimmune diseases and cancer. So, understanding cell signaling and the responses to the environment could facilitate drug discovery for the treatment of disease.

We are developing revolutionary nanotechnology that attacks two ends of the cell signaling problem. On the one hand, we use arrays of holographic optical traps to organize cells with nanometer precision into (permanent) synthetic tissue in a hydrogel matrix to study cell-to-cell communication. For example, as a model for paracrine signaling between neighboring cells, we have analyzed “quorum sensing” in genetically engineered bacteria. Quorum sensing is a regulatory mechanism that launches a coordinated multicellular response that depends on the population density—making the sum greater than the cellular parts. Figure 1 shows a confocal image of a $2 \times 2 \times 3$ array of *E. coli* that have been genetically manipulated to transmit (red) or receive (green) a particular signaling molecule acryl-homoserine lactone (AHL). In response to a broadcasted inducer (like IPTG) the transmitters produce AHL and a red fluorescent protein that is used as a reporter. The AHL diffuses through the cell membrane and the hydrogel into the receivers. If the AHL signal exceeds threshold, the receivers report by producing green fluorescent protein. As shown in Figure 1, eight transmitters are sufficient for signaling four receivers situated about $10 \mu\text{m}$ away along z —4 transmitters are insufficient.

On the other hand, we use nanopores in synthetic membranes to study the interactions between proteins and DNA that occur on the other end of the signaling network. In particular, using a synthetic nanopore in conjunction with a restriction enzyme, we have discovered a method for discriminating single nucleotide polymorphisms (SNPs) that occur when variants of the same gene (alleles) differ in one base. Since SNPs change the way that proteins are made, they form the basis for the differences that determine our individuality and vulnerability to disease.

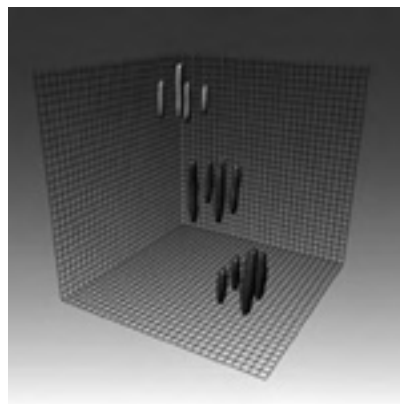


Figure 1. A false-color perspective iso-surface, reconstructed from volumetric data obtained from a series of confocal images, showing a $2 \times 2 \times 3$ three-dimensional array of *E. coli* that have been genetically manipulated into senders (dark) and receivers (light). When an inducer (IPTG) is broadcast to the array, the senders perceive IPTG in their microenvironment beyond a threshold and subsequently produce red fluorescent protein along with a molecular signal, AHL. If the concentration

is sufficient, the receivers produce green fluorescent protein. The dimension of each edge of the squares in the background is $1 \mu\text{m}$.

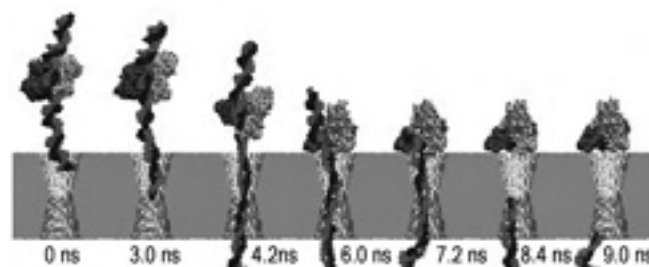


Figure 2. Snapshots taken from molecular dynamic simulations of EcoRI-DNA complex permeating a synthetic nanopore illustrating the dissociation of an EcoRI-DNA complex due to the electric field in a nanopore. The Si_3N_4 membrane is shown in grey, two strands of DNA in blue and green, a protein dimer in pink and purple, water and ions are not shown. Time elapsed from the moment a 4V transmembrane bias was applied is indicated in each snapshot.



Gregory Timp received his Ph.D. in Electrical Engineering from the Massachusetts Institute of Technology. He joined Bell Laboratories in 1988 where he pursued various aspects of nanostructure physics. As part of one collaboration, he investigated low temperature transport in electron waveguides; high mobility nanostructures so short that the transport is ballistic. In another effort, he explored the use of optical traps and laser focusing of single atoms for lithography applications. In a third, he explored the limits of silicon MOSFET technology—fabricating and testing some of the worlds smallest transistors. In 2000, he joined the Electrical and Computer Engineering Department at the University of Illinois. Since then he is been involved in research at the Beckman Institute applying nanotechnology to the study of biology. He is a fellow of the American Physical Society and American Academy of Nanomedicine.

Nanostructures and X rays for Nano Characterization

It is relatively rare for nature to be organized into uniform thin films! In this talk I will consider a nano-circle of developments: the fabrication of nanoscale diffractive focusing optics, their use for focusing nanometer wavelength soft X rays, and the use of these technologies to understand nanoscale heterogeneity of organic chemical speciation in biomaterials.

Fresnel zone plates produce the highest resolution far-field focus of electromagnetic radiation at any wavelength, with a resolution of 15 nm in special demonstrations [Chao et al., Nature 435, 1210 (2005)] and 30 nm in scanning microscopes operating at the carbon absorption edge [Spector et al., J. Vac. Sci. Tech. B 15, 2872 (1997); Lu et al., J. Vac. Sci. Tech. B 24, 2881 (2006)]. They involve very demanding nanofabrication requirements: high density curved diffraction gratings with high aspect ratio and high placement accuracy over large fields (see Fig. 1). These optics can then be used to focus coherent soft x-ray beams for scanning microscopy; by taking a regular series of images in the region of an x-ray absorption edge [Jacobsen et al. J. Micros. 197, 173 (2000)] and using pattern recognition algorithms for data analysis [Lerotic et al., Ultramic. 100, 35 (2004)], the natural organic chemical speciation properties of biomaterials can be uncovered with no prior information. This is of course aided by the development of x-ray sources with increasing brightness, and the Cornell energy recovery linac project could open up dramatic new capabilities.

One potential example with high potential impact involves biofuels research. Ethanol from corn grain exploits only a small fraction of the photosynthetic energy potential of plants, with at best modest net energy gains. On the other hand, cellulose is the most prevalent biomolecule on the planet so that if it could be freed from lignin and processed one could obtain dramatic increases in biofuel production from non-grain biomatter. Lignin and cellulose can be studied even in 400 million year old wood (Fig. 2) [Boyce et al., PNAS 101, 17555 (2004)], so x-ray microscopes offer perfect tools for studying various enzymes used for cellulose digestion. This is the subject of a new proposal involving physicists at Stony Brook, organic geochemists at Carnegie Institute of Washington, and molecular biologists at Cornell. We thank NSF, DoE, and NIH for support of various aspects of these studies.

Notes:

Christopher Jacobson

Professor of Physics & Astronomy
Dept. Physics & Astronomy
Stony Brook University

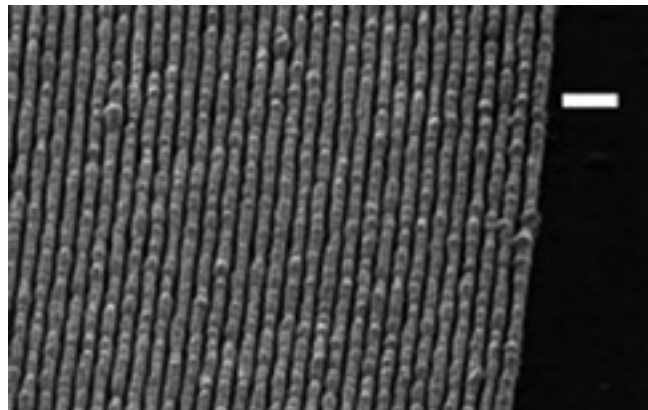


Figure 1.
30 nm half-pitch, 120 nm high Ni zones of a 160 μm diameter zone plate.

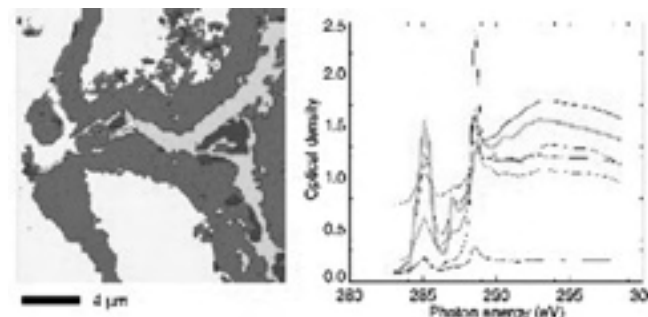


Figure 2.
Soft x-ray spectromicroscopy data of a 400 MYA chert wood (Boyce et al.).
Regions at left have carbon XANES spectra at right.

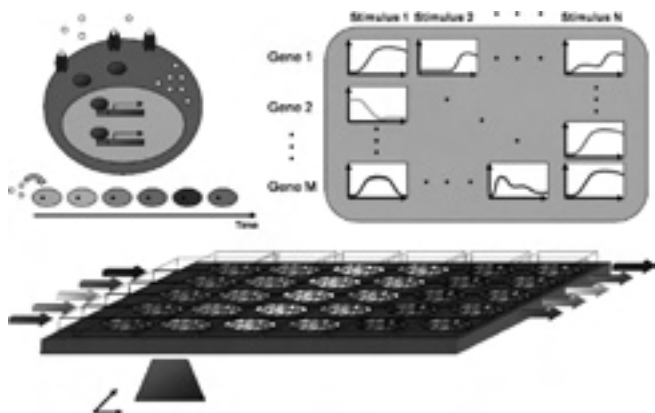


Chris Jacobsen is a Professor in Physics & Astronomy at Stony Brook University. His group carries out research in the development of x-ray microscopy methods and their application to problems in biology, environmental science, and energy research, including the nanofabrication of x-ray optics. He is a recipient of awards including a Presidential Faculty Fellowship (NSF/White House, 1992); the International Dennis Gabor award, and the Heinrich award, and is a fellow of the American Association for the Advancement of Science and the Optical Society of America.

Real Time Genomics for Analyzing Dynamic Cell & Tissue Processes

Martin Yarmush

Helen Andrus Benedict Professor of Surgery and Bioengineering
Harvard-MIT Division of Health Science and Technology,
Harvard Medical School
Director, Center for Engineering in Medicine,
Massachusetts General Hospital
Professor of Biomedical Engineering, Rutgers University



The tools of modern biology have revolutionized biomedical research, enabling an exponential growth in the acquisition of data regarding genes, proteins, and their structures and functions in normal and diseased states. Among these advances, the ability to monitor profiles of genes and protein expression accurately and on a large scale are notable. However, it is often not easy to correlate the trends and relationships observed in normal or abnormal states to the phenotype resulting from the gene expression profile. We are developing a new functional genomics approach for studying gene expression dynamics involving simultaneous measurement of temporal expression profiles of multiple genes. The technique relies on live cell imaging of fluorescence reporter cells in a microfabricated fluidically addressable cell array. This high throughput format allows parallel control of diverse soluble stimuli (concentrations, concentrations, and dynamics of cytokines, growth factors, and potential therapeutics) while allowing simultaneous noninvasive monitoring of gene expression at a single cell level. In this work our goals are to: 1) obtain the genes whose expression levels are altered by molecular mediators of the stress response and to generate green fluorescence protein (GFP)-tagged expression constructs of these genes; 2) use microfabrication and microfluidic techniques for developing a living cell microarrays where cells can be cultivated and exposed to multiple inputs; and 3) obtain temporal gene expression profiles using microarrays that have been exposed to combinatorial and temporally varying mixtures of stress mediators that closely mimic the physiological stress response. We hope to eventually use this information to predict the molecular events that determine a cell's progression to recovery or failure during stress.



Dr. Martin Yarmush is the Helen Andrus Benedict Professor of Surgery and Bioengineering in the Harvard-MIT Division of Health Science and Technology at the Harvard Medical School, and Director of the Center for Engineering in Medicine at the Massachusetts General Hospital (MGH). He received his BA degree (summa cum laude) in Biophysical

Chemistry at Yeshiva University, and carried out PhD work in Biophysical Chemistry at The Rockefeller University in the laboratories of Drs. Richard Krause and Thomas Kindt. He spent a postdoctoral year at the National Institutes of Health in the Laboratory of Immunogenetics before going to Yale for his MD degree. After three years at Yale, he entered the PhD program in Chemical Engineering at MIT, where he completed all requirements for a PhD degree in Chemical Engineering. In 1984, he joined the MIT Chemical Engineering department as a Principal Research Associate, where he established several interdisciplinary research programs in applied immunology, bioseparations, and tissue engineering. In 1988, Dr. Yarmush was recruited to Rutgers University, where he: 1) founded and directed the Rutgers-UMDNJ PhD Training Program in Biotechnology, 2) founded and directed the New Jersey Center for Biomaterials and Medical Devices, and 3) held the positions of Professor and Deputy Chair of Chemical and Biochemical Engineering. In 1995, he was recruited to Harvard Medical School and MGH to fill the positions that he currently holds. Over the last 25 years, Dr. Yarmush has published over 250 refereed journal articles (which collectively have > 6000 citations), has mentored > 35 graduate students and >80 postdoctoral fellows, and has taught a spectrum of courses from molecular genetics and immunology to thermodynamics and transport phenomena. A frequent invited speaker at major conferences and institutions, and winner of over 25 local and national awards, Dr. Yarmush is well known as one of the leading investigators in the area of molecular and cellular bioengineering through seminal contributions to the fields of liver and skin tissue engineering, applied immunology, genomics and proteomics technologies, and metabolic engineering. His research "pushes the envelope" on several healthcare technology frontiers through the use of state-of-the-art techniques that include microfabrication and nanotechnology, genomics and genetic engineering, advanced microscopic imaging, physiologic instrumentation, and numerical simulation. He has been credited with many pioneering scientific and technological advances including: innovative cell culture systems, bioartificial organs development, targeted therapies for tumors and infections, recombinant protein purification techniques, and recombinant retrovirus production and purification techniques. Some of these developments have resulted in patents and the formation of companies based on these advances.

Microchips for Cell-Based Systems in Biology and Clinical Medicine

Mehmet Toner

Massachusetts General Hospital
Harvard Medical School

Harvard-MIT, Division of Health Sciences and Technology

Biomedical applications of microfabricated devices is no longer limited to non-living systems as genes-on-a-chip or lab-on-a-chip, recent advances in the understanding of cellular behavior in micro-environments have started to pave the way toward living micro-devices. These emerging devices are expected to become key technologies in the 21st century of medicine with a broad range of applications varying from diagnostic, tissue engineered products, cell-based drug screening tools, and basic molecular biology tools. They will also include multiple cell types and/or genetically engineered cells to investigate complex interactions between cells from different tissues. These sophisticated devices will contain micro-engineered tissue units coupled to each other by complex microfluidic handling network. Microfluidic mixing systems will also precisely regulate the composition and concentration of drugs to be tested microchips to isolate rare cells from blood for diagnostics purposes. This presentation will briefly review the early historical literature on the use of microtechnologies in cellular systems and then focus on a number of applications.

Notes:



Dr. Mehmet Toner is a Professor of Surgery at the Massachusetts General Hospital (MGH) and Harvard Medical School. Dr. Toner is also a faculty member at the Harvard-MIT Division of Health Sciences and Technology. He is the principal investigator and serves as the Director of the BioMicroElectroMechanical

Systems Resource Center at MGH. Dr. Toner received a BS degree from Istanbul Technical University and an MS degree from the Massachusetts Institute of Technology (MIT), both in Mechanical Engineering. He subsequently completed his PhD degree in Medical Engineering at Harvard University-MIT Division of Health Sciences and Technology in 1989. Dr. Toner is a member of many national and international professional committees. He serves as the Associate Editor of the Journal of Biomechanical Engineering, Associate Editor of the Annual Reviews in Biomedical Engineering, member of the Editorial Board of the journals of Cryobiology and Cryo-Letters. In 1994, he was recognized by the Y.C. Fung Young Faculty Award in Bioengineering from the American Society of Mechanical Engineers (ASME). In 1997, he won the John F. and Virginia B. Taplin Faculty Fellow Award given by Harvard and MIT for his contribution to these two institutions in bioengineering research and education. In 2000, Dr. Toner was selected to become a Fellow of the American Institute of Medical and Biological Engineering.

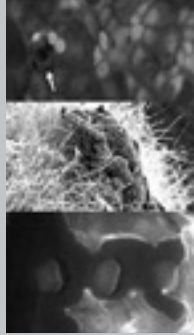
Notes:

Nanostructured Interfaces for Therapeutic Delivery

Tejal Desai

Professor of Physiology
Director UC San Francisco's Laboratory of
Therapeutic Micro and Nanotechnology
UC - San Francisco

Advances in micro and nanotechnology are creating new opportunities for therapeutic delivery. In this talk, I will explore strategies to target and penetrate cellular barriers that capitalize on the strengths of micro- and nanofabrication. By taking advantage of our ability to control chemical and topographical cues at submicron size scales, we can design organic and inorganic multiscale devices which modulate cell structure and function. We hypothesize that geometric control at multiple length scales, in addition to chemistry, can be used to enhance bioadhesion and tissue integration. Examples include nanoporous capsules for cellular delivery, microfabricated patches for oral drug delivery, and nanostructured thin films for ocular delivery. Such bioengineered interfaces may be optimized for biomolecular selectivity and surface bioactivity. Micro- and nanotechnology can add flexibility to current delivery practices while becoming an enabling technology for not only diagnostic applications, but also therapeutic platforms.



Dr. Tejal Desai is currently Professor of Physiology and Bioengineering at the University of California, San Francisco. She is also a member of the California Institute for Quantitative Biomedical Research and the UCSF/UC Berkeley Graduate Group in Bioengineering. Prior to joining UCSF, she was an Associate Professor of Biomedical Engineering

at Boston University and Associate Director of the Center for Nanoscience and Nanobiotechnology at BU. She received the Sc.B. degree in Biomedical Engineering from Brown University (Providence, RI) in 1994 and the Ph.D. degree in bioengineering from the joint graduate program at University of California, Berkeley and the University of California, San Francisco, in 1998. Dr. Tejal Desai directs the Laboratory of Therapeutic Micro and Nanotechnology. Her research combines methods and materials originally used for micro-electro-mechanical systems to create implantable biohybrid devices for cell encapsulation, targeted drug delivery, and templates for cell and tissue regeneration. In addition to authoring over 90 technical papers, she is presently an associate editor of *Langmuir*, *Biomedical Microdevices*, and *Sensors Letters* and is editor of an encyclopedia on Therapeutic Microtechnology. She has chaired and organized numerous conferences and symposia in the area of bioMEMS, micro and nanofabricated biomaterials, and micro/nanoscale drug delivery/tissue engineering. Her other interests include K-12 educational outreach, gender and science education, science policy issues, and biotechnology/bioengineering industrial outreach.

Desai's research efforts have earned her numerous awards. In 1999, she was recognized by *Crain's Chicago Business* magazine with their annual "40 Under 40" award for leadership. She was also named that year by *Technology Review Magazine* as one of the nation's "Top 100 Young Innovators" and more recently *Popular Science's* Brilliant 10. Desai's teaching efforts were recognized when she won the College of Engineering Best Advisor/Teacher Award. She also won the National Science Foundation's "New Century Scholar" award and the NSF Faculty Early Career Development Program "CAREER" award, which recognizes teacher-scholars most likely to become the academic leaders of the 21st century. Her research in therapeutic microtechnology has also earned her the Visionary Science Award from the International Society of BioMEMS and Nanotechnology in 2001, a World Technology Award Finalist in 2004, and the 2006 Eurand Grand Prize Award for innovative drug delivery technology.

Notes:

Understanding Cellular Mechanics Through Nanotechnology

Cellular mechanical functions involve the integration of mechanical sensing and cell motility to produce the desired morphology or motility in the organism¹. Nanometer level analyses of cell behavior have revealed only a limited number of types of motility involving complex mechanochemical steps². For example, cell spreading on matrix-coated surfaces have revealed three different types of motility, an initial blebbing, continuous spreading, and periodic contraction motility. In the case of periodic contraction motility that is also seen at the leading edge of migrating cells, motility proceeds by cycles of edge protrusion, adhesion and retraction and the period is dependent upon the width of the lamellipodial actin³. After careful examination of the process, we find that myosin II pulls the rear of the lamellipodial actin network causing upward bending, edge retraction and initiation of new adhesion sites. The network is then released from the edge and condensed over the myosin. Protrusion resumes as lamellipodial actin regenerates from the front and extends rearward until it reaches newly assembled myosin, initiating the next cycle. Upward bending, observed by evanescent microscopy and electron microscopy, is consistent with ruffling when adhesion strength is low. Correlative fluorescence and electron microscopy demonstrated that the regenerating lamellipodium forms a cohesive separable layer of actin (Giannone et al., 2007. Cell 128:561). Thus, actin polymerization periodically builds a mechanical link, the lamellipodium, connecting myosin motors with the initiation of adhesion sites, suggesting that major functions driving motility are coordinated through a biomechanical process. Overall, cell traction forces are primarily dependent upon myosin II⁴. In another type of motility, collagen fibers are pulled in by cells in a hand-over-hand fashion in a process that requires myosin IIB⁵. Because these different motility types are robust and occur in many different cell types, we suggest that most cell mechanical functions are accomplished by various combinations of these different motility types. Thus, it is important to define each type of motility at the nanometer level with the new nanotools that are available. Such a mechanistic understanding of cell function will open new ways to target specific cell functions that are critical for disease and wound repair.

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3. Giannone, G. et al. (2004) Periodic lamellipodial contractions correlate with rearward actin waves. Cell 116, 431-443.
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Michael Sheetz

William R Kenan Jr. Professor
Department Chair
Columbia University

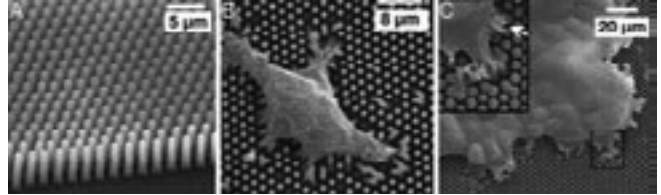


Figure 1. Pillar device used to measure the total force generated by cells on the substrate⁴. Image taken from du Roure et al., 2005 PNAS 102:5390.



Dr. Michael Sheetz is currently the William R. Kenan, Jr. Professor of Biological Sciences and Chair as well as Director of Nanotechnology Center for Mechanics in Regenerative Medicine. He holds a joint appointment in Biomedical Engineering at Columbia. Prior to joining Columbia, he was Chair of Cell Biology at Duke University Medical Center.

Past Accomplishments: He was a leader of the team that discovered kinesin and was involved in the early characterization of microtubule-dependent membrane traffic. He made many contributions to our understanding of membrane structure and physical properties that influence cell shape (bilayer couple hypothesis). Used laser tweezers to show that tension in membranes controls endocytosis, motility and healing rates.

Current Interests: Mechanosensing in the formation and regeneration of tissues; role of mechanical unfolding of substrates in tyrosine kinase phosphorylation and signaling. Definition of the mechanisms of cell motility at a mechanical and biochemical level. Understanding the membrane-cytoskeleton interface and its role in defining membrane function.

Notes:

Biologic Length Scale Topographic Features Modulate Cell Behavior

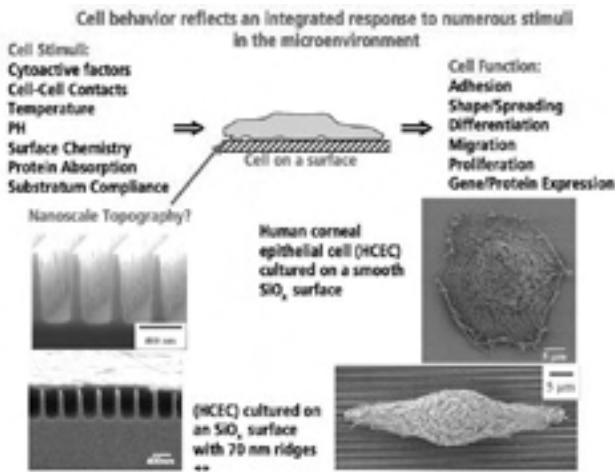
Christopher Murphy

Professor, Dept. of Surgical Sciences, School of Veterinary Medicine
University of Wisconsin-Madison



Christopher Murphy received his BS, DVM and PhD degrees from Cornell University. He completed his training in comparative ophthalmology at the Veterinary School at UC, Davis and then went to the Medical School to complete a combined clinical and research fellowship in corneal disease and surgery of the anterior segment.

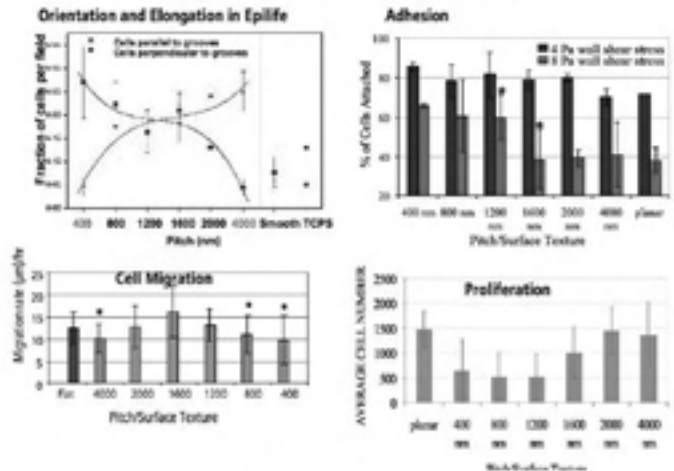
He became a faculty member at the Medical School at UC Davis before moving to UW-Madison where he has been for the past 16 years. His laboratory is interdisciplinary with strong collaborative ties to the schools of Engineering and Medicine. He has 4 discrete areas of research ongoing in his laboratories with the majority of his time spent on investigating how topographic cues provided through the extracellular matrix modulate fundamental behaviors in diverse cell types. His laboratory is funded from multiple institutes at the NIH as well as the NSF and industry sources. He has published over 145 peer reviewed papers as well as a childrens book. He is a co-founder of a biotech startup company and serves as director of the Comparative Ophthalmic Research Laboratories.



There is increasing evidence that the complex three-dimensional structure of the basement membrane provides topographic cues that modulate fundamental cell behaviors, independent of specific receptor ligand interactions. Previously published reports have demonstrated that basement membranes consist of fibers, pores and elevations in the 20-400 nm range. Investigating a variety of cell-types, including corneal epithelial cells, keratinocytes, fibroblasts, vascular endothelial cells, urothelial cells and PC-12 cells we have demonstrated the profound impact of nanoscale and submicron topographic features on a range of cell phenotypes. For each studied behavior including orientation, proliferation, migration and adhesion we have found that a transition in cellular response to topography occurs in between 1200 nm and 1600 nm pitch (ridge widths of 400 to 900 nm). Cell proliferation decreases and cell adhesion increases on the smallest feature sizes below 1µm and migration rates are the highest right at the zone of transition. We also note that the phenotypic response could be influenced by cell-type. Finally, we have recently found that topographic cues encourage retention of self-renewal properties for human embryonic stem cells under culture conditions that promote self-renewal and encourage cellular differentiation under culture conditions that promote differentiation. We conclude that biologically relevant nanometer length features are important regulators of cellular behavior. These findings have immediate relevance to the interpretation of in vitro data obtained on flat plasticware, emerging strategies in cell, stem cell and tissue engineering and the development of prosthetic devices.

He became a faculty member at the Medical School at UC Davis before moving to UW-Madison where he has been for the past 16 years. His laboratory is interdisciplinary with strong collaborative ties to the schools of Engineering and Medicine. He has 4 discrete areas of research ongoing in his laboratories with the majority of his time spent on investigating how topographic cues provided through the extracellular matrix modulate fundamental behaviors in diverse cell types. His laboratory is funded from multiple institutes at the NIH as well as the NSF and industry sources. He has published over 145 peer reviewed papers as well as a childrens book. He is a co-founder of a biotech startup company and serves as director of the Comparative Ophthalmic Research Laboratories.

Transitions Occur at a Length Scale of 400-800 nm (800-1600 nm pitch)



Notes:

When Bio-Molecules Affect Flow

Dorian Liepmann

Associate Professor
Mechanical Engineering
University of California

BioMEMS and microfluidics have enabled new technologies by providing new approaches for biosensors, diagnostic systems, and biomedical research. Many, if not most, biomedical applications will involve fluid control of complex and two-phase fluids where large biomolecules and polymers interact at the nanometer and micron length scales. In this arena, the characteristic length scales of cells, large molecules, and functionalized beads are similar to the length scales of the micro-flow channels in a way that does not exist in the macro-world. Researchers at Cornell were among the first scientists to recognize the importance and interesting nature of these complex flows and as a result much of the original work in this area was pioneered at the Cornell NanoScale Science and Technology Center. Current research being done at BSAC and Berkeley on the interaction of polymers and microflows focusing on biomolecules (DNA) as well as more complex triblock copolymers will be presented. The talk will focus on situations that exhibit unexpected results for which we are still looking for answers.

Notes:



Dorian Liepmann received his PhD in Applied Mechanics (Fluid Mechanics) in 1990 from UC San Diego. In 1993, he joined UC Berkeley as an Assistant Professor in the Mechanical Engineering Department. He is now Chair of the Bioengineering Department. In addition, he is a co-director of the Berkeley Sensor & Actuator Center (BSAC).

Dr. Liepmann and his group have been involved in microfluidics research for over ten years and have worked on the development of MEMS-based fluid control devices including mixers, valves and pumps. He is currently working on the development of systems for controlled drug-delivery and rapid diagnostics as well as performing fundamental research on fluid mechanics at micron-scales.

Notes:

Anticipatory Governance and Reflexivity: A Means for Real-time Technology Assessment

David Guston

Professor of Political Science

Director, Center for Nanotechnology in Society
Arizona State University

The Center for Nanotechnology in Society at Arizona State University (CNS-ASU) is an NSF-funded center, created in October 2005, for research, education and outreach on the societal aspects of nano-scale science and engineering (NSE). CNS-ASU involves the collaboration of scores of faculty, students, and staff in more than half a dozen universities across the country. To provide coherence to its broad programs, CNS-ASU attempts to implement “real-time technology assessment” – a vision of social science research, in close collaboration with NSE research – which promotes the possibility of increased “reflexivity” among the NSE researchers themselves and the “anticipatory governance” of emerging nanotechnologies. By reflexivity we mean the ability of researchers to be more aware of the kinds of decisions they are making, on behalf of society, in their research. By anticipatory governance, we mean the ability of a variety of stakeholders and the lay-public to prepare for the issues that NSE may present before those issues are manifest or reified in particular technologies. This presentation will explicate what CNS-ASU means by real-time technology assessment, focusing in particular on how its developing research programs attempt to increase the capacities for reflexivity and anticipatory governance.



Professor David Guston is Principal Investigator and Director of the Center for Nanotechnology in Society at Arizona State University. CNS-ASU is a National Science Foundation-funded Nanoscale Science and Engineering Center dedicated to studying the societal implications of nanoscale science and engineering research and improving the societal outcomes of nanotechnologies through enhancing the societal capacity

to understand and make informed choices.

Professor Guston’s book, *Between Politics and Science: Assuring the Integrity and Productivity of Research* (Cambridge U. Press, 2000) was awarded the 2002 Don K. Price Prize by the American Political Science Association for best book in science and technology policy. He has also co-authored *Informed Legislatures: Coping with Science in a Democracy* (with Megan Jones and Lewis M. Branscomb, University Press of America, 1996) and co-edited *The Fragile Contract: University Science and the Federal Government* (with Ken Keniston, MIT Press, 1994). *Shaping the Next Generation of Science and Technology Policy*, co-edited with CSPO director Daniel Sarewitz, will be published in autumn 2006 by University of Wisconsin Press.

Professor Guston has published numerous articles and book chapters and made more than seventy research presentations on research and development policy, scientific integrity and responsibility, public participation in technical decision making, peer review, and the politics of science policy. He is the North American editor of the peer-reviewed journal *Science and Public Policy*, and he serves on the editorial boards of *Nanoethics: The Ethics of Technologies that Converge at the Nanoscale*, and *VEST: Nordic Journal of Science and Technology Studies*.

Professor Guston has served on the National Science Foundation’s review panel on *Societal Dimensions of Engineering, Science, and Technology* (2000-2002) and on the National Academy of Engineering’s Steering Committee on *Engineering Ethics and Society* (2002). In 2002, he was elected a fellow of the American Association for the Advancement of Science. He holds a B.A. from Yale and a PhD from MIT.

Notes:

Mind the Gap: Social and Ethical Research in Nanotechnology and International Security

It is generally accepted that nanotechnology (NT) is going to revolutionise how humankind will produce, communicate, live, maybe even what we are. With large potential benefits come large risks. This has been acknowledged by national and supranational NT initiatives, and they have stressed the need for research of ethical, legal and societal implications of NT from the beginning. Much focus is on unintentional damage, e.g., from accidental release of nanoparticles into the environment, or from various secondary effects. Very little analysis is devoted, however, to intentional destructive uses. These are prepared in military research and development for future application in armed conflict. Under the goal of attaining technological superiority as a central means of achieving military victory, striving for early use of all new technological possibilities seems the way to go. However, if one takes a wider view, taking into account interactions and feedback cycles on the international level, security of countries will more often than not deteriorate by an open-ended technological arms race.

I have sifted potential military applications of NT with a view toward international peace and stability. Whereas many military uses would parallel civilian ones, several pose new, strong dangers. Among these applications are small missiles, combat robots and selective biochemical warfare agents. Particular instability could result from microrobots pre-deployed inside military systems of a potential enemies. Body manipulation applied in armed forces could pre-empt a broad societal debate on benefits, risks and regulation. Containing such dangers is possible by preventive limitation, embedded in a general framework of arms control and disarmament.

Because the US at present is spending 80 to 90 % of the world-wide expenditure for military R&D of NT, it has a pivotal role – setting a precedent in wide-spread introduction of new NT-based military systems, or acting as a leader in global cooperative limitation.

Notes:

Jürgen Altmann

Experimentelle Physik
Universität Dortmund, Essen, Germany



Jürgen Altmann studied physics and did a doctoral dissertation on laser radar (University of Hamburg, Germany, 1980). Following research work in computer pattern recognition he has, since 1985, studied scientific-technical problems of disarmament, first concerning high-energy laser weapons, then European ballistic-missile defence. In 1988 he founded the Bochum Verification Project

(Ruhr-University Bochum, Germany) which does research into the potential of automatic sensor systems for cooperative verification of disarmament and peace agreements. Prospective assessment of new military technologies and analysis of preventive-arms-control measures form another focus of his work, with studies of non-lethal weapons, military uses of microsystems technologies and of nanotechnology¹ (done at University of Dortmund, Germany). He was a member of the expert group on converging technologies for the European Commission. He is a co-founder of the German Research Association for Science, Disarmament and International Security (FONAS) and a deputy speaker of the Committee on Physics and Disarmament of the German Physical Society (DPG).

References

1. J. Altmann, Military Nanotechnology: Potential Applications and Preventive Arms Control, Abingdon/New York: Routledge, 2006

Notes:

Science Fiction as a Portal to Ethics in Nanotechnology



It is often taken for granted that nanotechnology is simply a morally neutral technological evolution arising from human curiosity, ingenuity, and enterprise. In fact, there is moral significance in the imagined possibilities, in beliefs and visions, and especially in the individual searches for meaning reflected in conceptualizations of nanotechnology. Its pursuit is situated in the hopes and dreams of its creating research scientists and engineers, in whom society vests its own fears, desires, and aspirations.

Third Dimension Nano-ethics entails the search for an understanding of the meaning and significance of nanotechnology as it pertains to beliefs about existence; conceptualizations of self and other; and purpose in living. Its access is through myth, art, and other symbolic languages. In this dimension of ethical consideration, the moral agent encounters himself in the strangeness of what is imagined to be, and codifies the most meaningful of those images in symbolic terms. It is rooted in endeavors of the moral imagination; the ability to discern possibilities for action and to imagine its consequences.

Narratives which are expressive of the moral imagination, can fall into one or more overlapping categories, including fiction, non-fiction, or myth. Narratives are ubiquitous in human life: all humans have stories. Stories can be personal, familial, communal or national. Just as human beings are inherently imaginative creatures, so are they adept story-tellers.

As a form of narrative production, fiction allows us to loosen our clutch on that which has “actually happened,” permitting our imaginations to explore more than what we, as individuals and as members of particular societies, know. It enables its readers and writers alike to investigate extrapolations of reality towards the goal of understanding that which already exists. Using the venue of science fiction to reflect on the ethical implications of nanotechnology enables us not only to conceptualize various possible futures, but to also reveal otherwise tacit dreams, fears and hopes, through the imaginative process.

Rosalyn Berne

Associate Professor
Department of Science, Technology and Society;
School of Engineering and Applied Sciences
University of Virginia



Professor Berne's research focuses on the ethical, cultural, and societal implications of nanotechnology, and its convergence with biotechnology, information technology and cognitive sciences. She is particularly interested in the role and function of the moral imagination; mythology; and religious belief in conceptualizations pertaining to

ethics in technological development. These she has explored and discussed in her book Nanotalk: Conversations with Scientists and Engineers about Ethics, Meaning and Belief in the Development of Nanotechnology (Erlbaum, 2005). The examination continues in her next book on the subject, Nanotechnology and the Moral Imagination (in progress). Also of both scholarly and personal concern to Berne is the role of emerging technologies in the ethics of procreation. Berne has recently turned to science fiction writing as both a source of data, and a source of deliberation about the future of radical, socio-technical change in the world. She has recently finished her first novel, *Waiting in the Silence*, which explores the nature of womanhood, procreation, aging and spirituality, as these may be in a nanotechnology driven, socio-technical future.

Rosalyn Berne has served as Executive Director of the Olsson Center of Applied Ethics; Director of Admission of the Darden School; University of Virginia Assistant Vice President of Administration; and Head of School for Tandem Friends School in Charlottesville, VA. She received a Ph.D. in Religious Studies/Bio Ethics from the University of Virginia.

Notes:

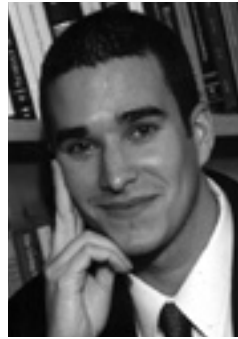
Ecologic: Complexity, Cognition, and the Regulation of Nascent Technologies

Douglas Kysar

Professor of Law
Cornell Law School

Two distinct approaches to policymaking - associated with cost-benefit analysis and the precautionary principle - currently compete for dominance in the area of environmental, health, and safety regulation. The first aspires to achieve comprehensive rationality by identifying all anticipated consequences of regulatory action or inaction, translating such consequences into a common currency that is said to reflect their impact on human welfare, and, finally, selecting the course of conduct that maximizes expected aggregate welfare according to the analyst's calculations. The second approach eschews attempts to optimize in this fashion and instead regards environmental, health, and safety decision making as an unavoidably pragmatic, yet nevertheless urgent, duty to safeguard life in a world of uncertainty and complexity. This presentation will examine certain normative and methodological characteristics of these two approaches within the context of nascent technology regulation. It will be shown that, despite the heated rhetoric often exchanged by their proponents, the two approaches actually exhibit complementary inadequacies, and that what truly is needed in the domain of risk regulation are policy tools that exhibit symmetric humility before natural and social systems.

Notes:



Douglas Kysar is Professor of Law at Cornell University where he teaches and writes in the areas of tort law, products liability, risk regulation, environmental law, and sustainable development. He has been a visiting faculty member at Harvard and Yale Law Schools, a visiting scholar at the Universitat Pompeu Fabra in Barcelona, Spain, and a Distinguished Environmental

Law Lecturer at the Florida State University College of Law. He graduated magna cum laude in 1998 from Harvard Law School, where he received the Sears Prize and was a member of the Board of Student Advisors. Following law school, Professor Kysar clerked for the Hon. William G. Young, Chief Judge for the U.S. District Court of Massachusetts, and practiced corporate law with Foley, Hoag, & Eliot LLP in Boston. Since joining the faculty at Cornell in 2001, he has twice been elected convocation speaker by the graduating J.D. class. He has published widely on competing policymaking paradigms for the regulation of nascent technologies, examining in particular certain underappreciated moral and political assumptions that underlay invocation of cost-benefit analysis and the precautionary principle within intergenerational policymaking contexts. He is presently at work on a book-length treatment of these subjects, [The Point of Precaution: Economics and the Forgetting of Environmental Law](#). In late 2006, Professor Kysar began serving as Societal and Ethical Issues Coordinator for the National Nanotechnology Infrastructure Network.

Notes:

Social and Ethical Dimensions of Nanotechnology: Research and Education Activities

Priscilla Regan

Professor of Government and Politics
Department of Public and International Affairs
George Mason University
Program Director, Science and Society Program
National Science Foundation
June 11, 2005 - June 11, 2007

This presentation will provide an overview of key National Science Foundation (NSF) funded research and educational activities regarding social and ethical dimensions of nanotechnology. First, the requirements of the US 21st Century Nanotechnology R&D Act of 2003 will be described. Second, research regarding social and ethical issues associated with nanotechnology will be categorized and discussed along five dimensions – ethics; public deliberation and participation; science policy of nanoscale science and engineering; regulatory capacity; and risk perceptions. Finally, challenges of identifying and analyzing the longer-term societal dimensions of nanotechnology will be explored.

Notes:



Priscilla Regan is a Professor of Government and Politics at George Mason University. From June of 2005 to June of 2007, she was one of two Program Directors in the Science and Society Program at the National Science Foundation where she managed awards regarding the social and ethical implications of nanotechnology. She was also responsible for proposals in ethics

and values of science, engineering and technology and in studies of policy, science, engineering and technology. Prior to joining the GMU faculty in 1989, she was a Senior Analyst at the Congressional Office of Technology Assessment. Her research involves analyses of the social and legal implications of new communications and information technologies, with particular attention to their privacy implications. She is also doing research on e-government initiatives, especially how they affect congressional-executive relations. She has a PhD in Government from Cornell University.

Notes:

2007 CNF
30th Anniversary Celebration
Letters of Congratulation



CONGRESSMAN MAURICE D. HINCHEY
U.S. HOUSE OF REPRESENTATIVES

January 30, 2007

Dear Dr. Malliaras,

I would like to take this opportunity to congratulate you and your colleagues on the thirty years of service the Cornell NanoScale Science and Technology Facility has devoted to the scientific community and world at large.

CNF aids in maintaining Cornell's rightful position as one of the world's most important and progressive institutes. The study of nanoscience is an essential component in ensuring the successful future of physical science, engineering, and life science. I consider the work that you do a great source of pride, and regard CNF as a valuable asset to the congressional district I am privileged to represent.

I look forward to witnessing your continued good works.

Best wishes,

A handwritten signature in black ink, appearing to read "Maurice D. Hinchey".

Maurice D. Hinchey
Member of Congress

CHAIR

COMMITTEE ON INVESTIGATIONS
AND GOVERNMENT OPERATIONS

LEGISLATIVE COMMISSION ON
RURAL RESOURCES

COMMITTEE MEMBER

CRIME VICTIMS, CRIME & CORRECTION

ELECTIONS

ENERGY & TELECOMMUNICATIONS

HEALTH

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April 16, 2007

Dear Dr. Malliaras:

First and foremost, I'm extremely pleased for this opportunity to extend my warmest greetings to all those attending this celebration of the 30th Anniversary of the Cornell NanoScale Science and Technology Facility (CNF).

We sincerely appreciate your participation and hope that your stay here will be meaningful and memorable.

As well, I'm proud to express my congratulations to you and to all those, past and present, who have worked so diligently over the past three decades to make the CNF one of the world's premiere research and development facilities. I hope that all of you take well-deserved pride in your achievements and contributions in the fields of engineering, science and technology.

I couldn't be more grateful to represent the CNF and all of Cornell University. Your remarkable contributions are central to the quality of my 53rd State Senate District.

Congratulations again on 30 years of success, and my very best wishes for a meaningful and memorable symposium.

Sincerely,

A handwritten signature in black ink, appearing to read 'G. Winner, Jr.', written over a horizontal line.

NYS Senator George H. Winner, Jr.
53rd Senatorial District



BARBARA LIFTON
Member of Assembly
125th District

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May 5, 2007

Cornell NanoScale Science and Technology Facility
Cornell University
Ithaca, NY 14850

To all my friends at Cornell:

On behalf of the State of New York, and the 125th Assembly District, I want to offer congratulations on 30 years of innovation and exciting research at the Cornell NanoScale Science and Technology Facility.

The ground-breaking discoveries made at the facility in the fields of engineering and the physical and life sciences will direct scientific research for many generations to come. Nanoscience is critical to our future, and the Cornell facility remains at the forefront of this research.

Thank you for 30 years of service to the scientific community, and I look forward to the next 30!

Sincerely,

Barbara S. Lifton
Member of Assembly
125th District

BSL/rd



House of Lords, London SW1A 0PW

May 11, 2007

Professor George Malliaras,
Director
Cornell NanoScale Science and Technology Facility
250 Duffield Hall
Ithaca, New York 14853-2700

Dear George,

I write to congratulate you and all those who have contributed to Cornell's NanoScale Science and Technology Facility over the past thirty years. The accomplishments of the Facility have been quite extraordinary and far exceed those that any of us who were around in 1977 could have predicted. They have earned it an international reputation that is a huge credit to Cornell University.

My association with the CNF goes back to the time when it was being planned - I forget exactly when that was but it must have been in 1976 - about the time we at IBM first realised that it was possible to make sub-10 nm structures with e-beams. I remember how pleased I was that Cornell's bid, which was led, if my memory does not fail me, by Joe Ballantyne, won the NSF contract, and then that my friend Ed Wolf had been persuaded to abandon the Californian sunshine and Hughes, Malibu and take on the pioneering task of being the first Director.

Since then there have been a succession of highly talented Directors who have attracted to the Facility an abundance of outstanding researchers who have ensured that the Facility maintained its international leadership in this rapidly changing field. The basic principles were laid at the beginning; that the capabilities of the Facility were to be accessible as widely as possible and that the applications to which they were to be applied were unconstrained. Diversity was encouraged and this has born fruit remarkably. Cell biology has the same priority as semiconductor devices and this has enabled the type of cross-disciplinary research that excites everyone in all fields of high technology to flourish.

May I extend my warm congratulations to all of you who have made CNF what it is today?

With every good wish,

Alan



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Sandip Tiwari
*Charles N. Mellome Professor of
Engineering*
Director, NNIN

Cornell University
410 Phillips Hall
Ithaca, NY 14853-5201

Telephone: 607 254-6254
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June 8, 2007

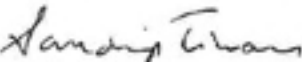
Professor George Malliaras
Lester B. Knight Director
Cornell Nanoscale Facility
Cornell University
Ithaca, NY 14853

Dear George:

The Cornell Nanoscale Facility has been the fountain of numerous scientific discoveries, a catalyst for a large number of engineering breakthroughs, has seeded hundreds of companies, and has been central to the educational and research development of many thousands of graduate students across the nation – any one of these accomplishments would make any organization very proud.

My thank you for all for CNF's vital contribution to the nation and to Cornell, and I wish you a very stimulating 30th anniversary celebration.

Regards,


Sandip Tiwari

HILLARY RODHAM CLINTON
NEW YORK



United States Senate
WASHINGTON, D. C. 20510-3204

June 14, 2007

Dr. George Malliaras
Lester B. Knight Director
Cornell NanoScale Science & Technology Facility (CNF)
250 Duffield Hall
Cornell University
Ithaca, NY 14853

Dear Dr. Malliaras and Members of the Cornell Nanoscale Community:

Congratulations to all on your commitment to outstanding scientific research exemplified by thirty years of achievement at the Cornell NanoScale Science and Technology Facility.

The amazing research that this facility has accomplished expands the frontiers of science, and your discoveries and advancements in the fields of engineering, the physical sciences and the life sciences have improved the quality of life for countless individuals.

Keep up the exciting work! Our future depends on such high-quality scientific research.

Sincerely yours,

A handwritten signature in black ink that reads "Hillary Rodham Clinton". The signature is fluid and cursive, with a long, sweeping underline.

Hillary Rodham Clinton

CHARLES E. SCHUMER
NEW YORK

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United States Senate

WASHINGTON, DC 20510

June 14, 2007

Dr. George Malliaras
Lester B. Knight Director
Cornell NanoScale Science and Technology Facility
250 Duffield Hall
Cornell University
Ithaca, NY 14853-2801

Dear Dr. Malliaras, CNF faculty, students, and staff:

I write today to congratulate the Cornell NanoScale Science & Technology Facility and its dedicated team on thirty years of scientific research and advancement. As an integral part of the scientific community since 1977, CNF has evidenced itself to be a remarkable asset to the world of technological discovery.

Spanning the fields of the physical sciences, engineering, and the life sciences, CNF has provided its staff, equipment and facilities to some of the leading minds across the nation in pursuit of scientific exploration and innovation. I commend the Cornell NanoScale Science & Technology Facility for having set the standard for high quality nanoscience research and am certain that CNF faculty, students, staff, and researchers will continue to strive for excellence in the many years to come.

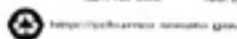
Again, congratulations and thank you for your work and contributions to the ever-expanding field of nanoscience technology.

Sincerely,

Charles E. Schumer
United States Senator

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Cornell University

David J. Skorton
President

June 14, 2007

Dr. George Malliaras
Lester B. Knight Director
Cornell NanoScale Science and Technology Facility
250 Duffield Hall
Cornell University
Ithaca, NY 14853-2801

Dear Professor Malliaras:

Congratulations to you and the faculty, staff, students and distinguished outside visitors who have contributed to the success of the Cornell NanoScale Science and Technology Facility since its inception 30 years ago.

During its three decades of operation, CNF has made outstanding contributions to the education of future nanoscale scientists and provided a model for other nanofabrication facilities. The facility draws researchers from across the physical sciences, life sciences and engineering, many of whom use CNF's resources to carry out critical, interdisciplinary work.

With users drawn from industry, government, and other academic institutions, as well as from Cornell, CNF is truly a national resource that has kept Cornell at the forefront of nanoscale science and technology.

As you celebrate the successes of the past 30 years, I offer you and your colleagues best wishes for continuing leadership in teaching, research and outreach.

Best regards,

A handwritten signature in cursive script that reads "David J. Skorton".

David J. Skorton
President

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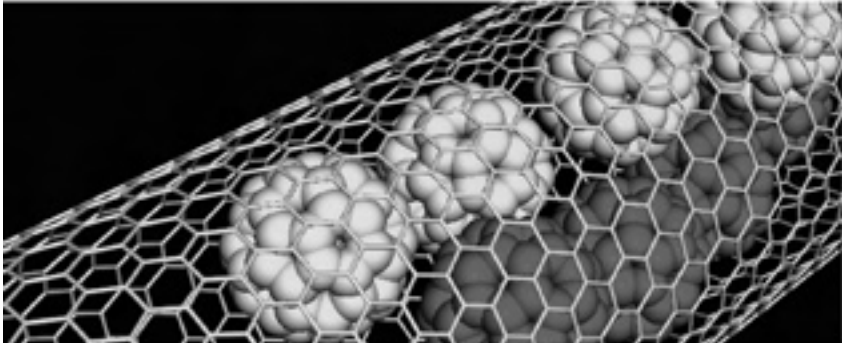
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